Summary: LAr detectors

Sebastien Murphy ETHZ

NNN 1999

Home

NNN Page

Initial Announcement of the Workshop, December 1998

First Bulletin

Second Bulletin in PDF, PS format

Registration

Scientific Program

Working Groups

Transparency Scans (under construction)

Photo taken durring the workshop (under construction)

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NNN99 Workshop

- International Workshop on Next Generation Nucleon Decay and Neutrino Detector -
- September 23-25, 1999 -
- The State University of New York at Stony Brook -

NNN99

nnn99@superk.physics.sunysb.edu

Last modified: Wed Oct 27 18:05:57 EDT 1999

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NNN99

one talk on large liquid argon detectors.

Nucleon decay studies in a large Liquid Argon detector

M.Campanelli

A.Bueno

A.Rubbia

a fundamental open problem

on is open, no possibility can be

l event imaging is very powerful

and is probably essential in case

has developed for 10 years the

e large mass Liquid Argon TPC

decay physics

limitation in reaching very large masses (O(30 kton)) with this technology

- Most of the decay channels are basically background-free, so the sensitivity grows linearly with exposure and mass
- Nuclear reinteractions play a large role in efficiency determination, so they should be properly treated
- Even with smaller mass with respect to other technologies, the discovery potential of this kind of detector is very good
- Nucleon decay requires patience... hopefully not infinite.

This weeks LAr agenda

more than 15 talks (and as many posters)

NNN 2015
stony Brook

- Parallel:
- The present status of ICARUS and its next future at Fermilab. Alessandro Menegolli (PV)
- Charge readout and construction of the first WA105 large Double Phase Liquid Argon TPC. *WU, Shuoxing (ETH Zurich)*
- Status & plans of the WA105 6x6x6 m3 Double Phase Liquid Argon TPC at CERN neutrino platform. *BOLOGNESI, Sara (CEA Saclay)*
- DUNE Single Phase Liquid Argon TPC prototyping at CERN and Fermilab INSLER, Jonathan
- Captain: Status and plans for cross-sections measurements relevant for DUNE WHITEHEAD, Lisa (U. of Houston)
- ArgoNeut&Lariat: Status and plans for cross-sections measurements relevant for DUNE FLANAGAN, Will
- Towards realisation of very high voltage for Liquid Argon TPCs: present R&D status and future challenges LOCKWITZ, Sarah (Fermilab)
- Overview of light readout solutions applicable to large underground Liquid Argon TPCs SZELC, Andrej (Manchester)
- Triggering and charge readout of Liquid Argon TPCs from MeV to multi-GeV TSAI, Yun-Tse (SLAC)

- Plenary:
- First Look at MicroBooNE CARLS, Benjamin (Fermilab)
- FNAL short baseline program GUENNETTE, Roxanne (Oxford U.)
- Status of DUNE@LBNF KUTTER, Thomas (LSU)
- Review of LAr TPC event reconstruction: Progress and Challenges STEFAN, Dorota (CERN/NCBJ)
- DUNE Strategy for Controlling Systematic Uncertainties WORCESTER, Elizabeth (Brookhaven National Lab)
- Liquid Xe detectors for double beta decay and connection with large LAr detectors, POCAR, Andrea

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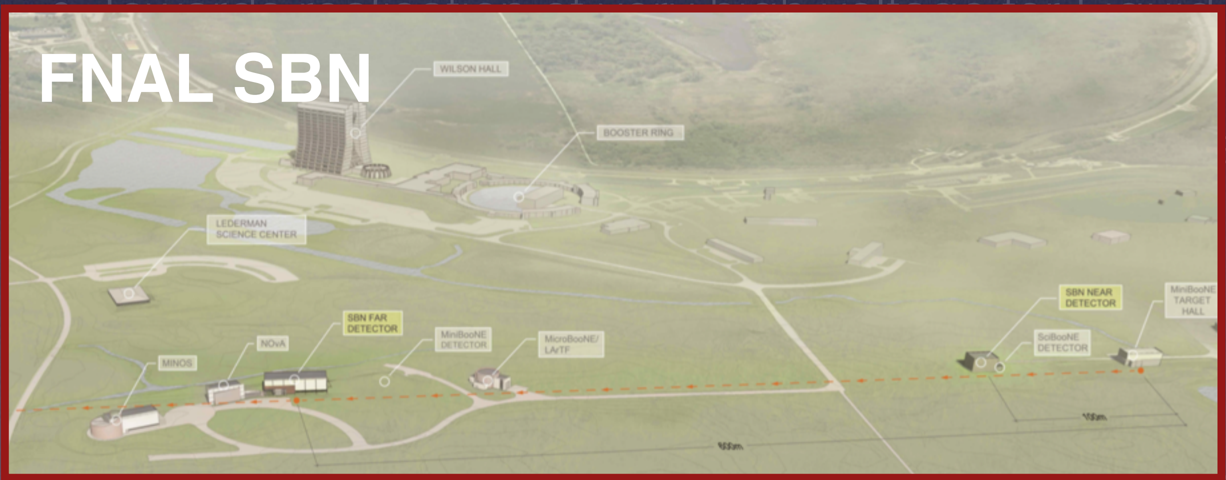
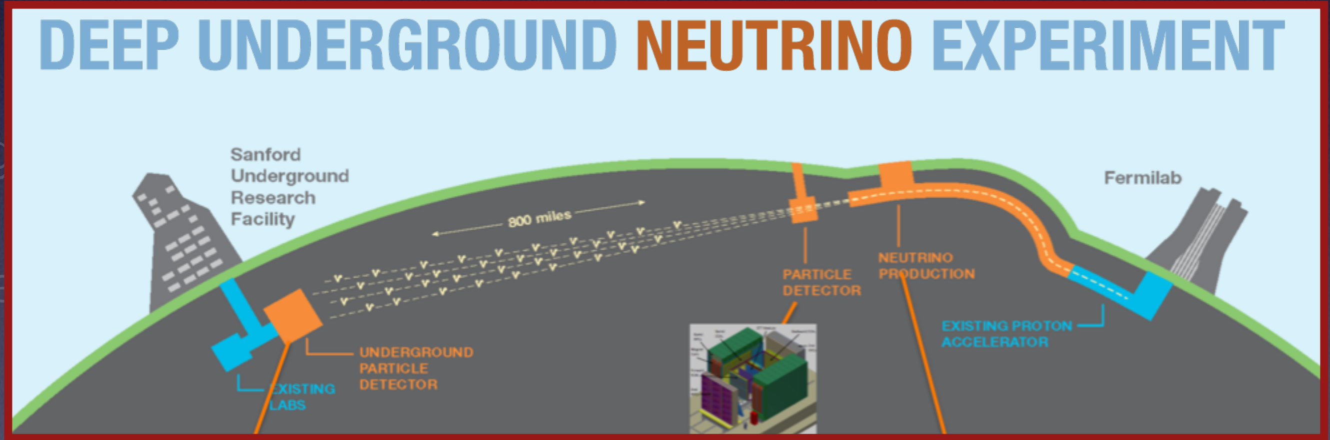
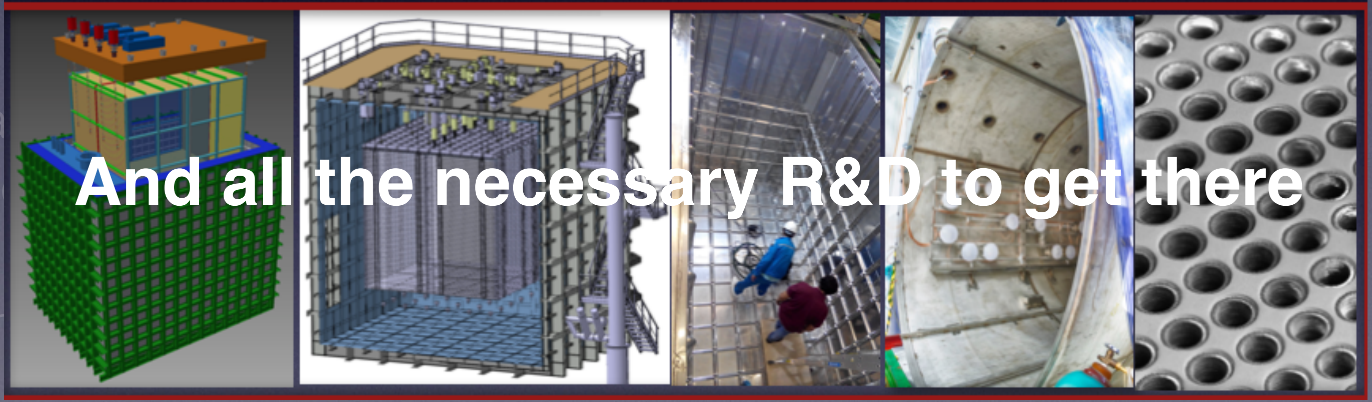
It is maybe the first NNN where the international community has a clear roadmap and is bound together by large scale and ambitious projects at the 2020+ timescale.





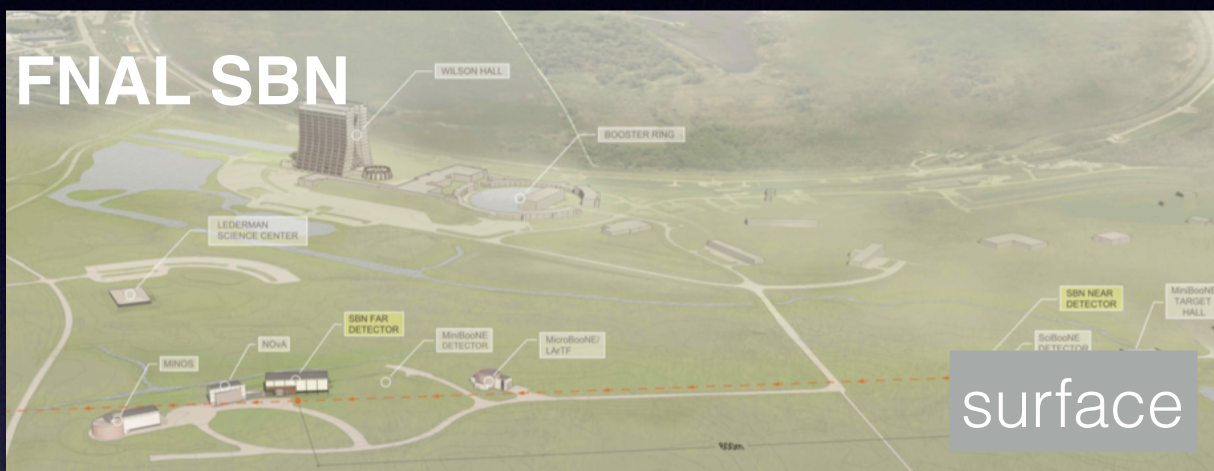


Near future: the driving experiments

short baseline

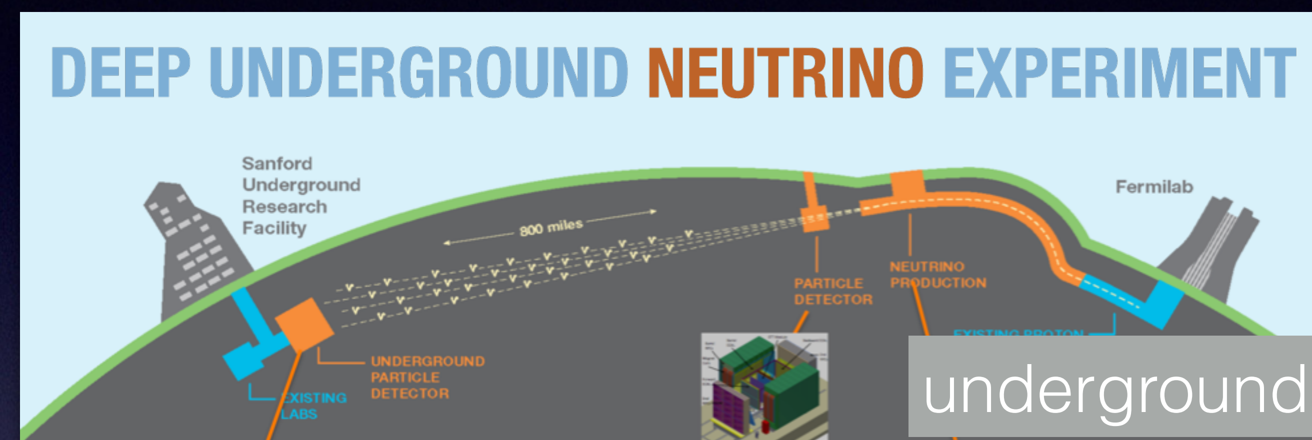
long baseline

<700 MeV> - 600 m - L/E ~1 km/GeV



- Understand the LSND and MiniBooNE low energy excess of ν_e, $\bar{\nu}_e$.
- "beyond θ_{13}" disappearance signal in low energy electron anti-neutrinos from nuclear reactors.
- convincing cases for the existence (or not) of sterile neutrinos

<2 GeV> - 1500 km - L/E ~1000 km/GeV



- The ordering of the neutrino masses
- the discovery of CP-violation in the lepton sector
- the unambiguous observation of nucleon decay
- the possible observation of unpredicted rare events

$\nu_\mu \rightarrow \nu_e$ appearance experiments
Eν 1-10 GeV

Near future: the driving experiments

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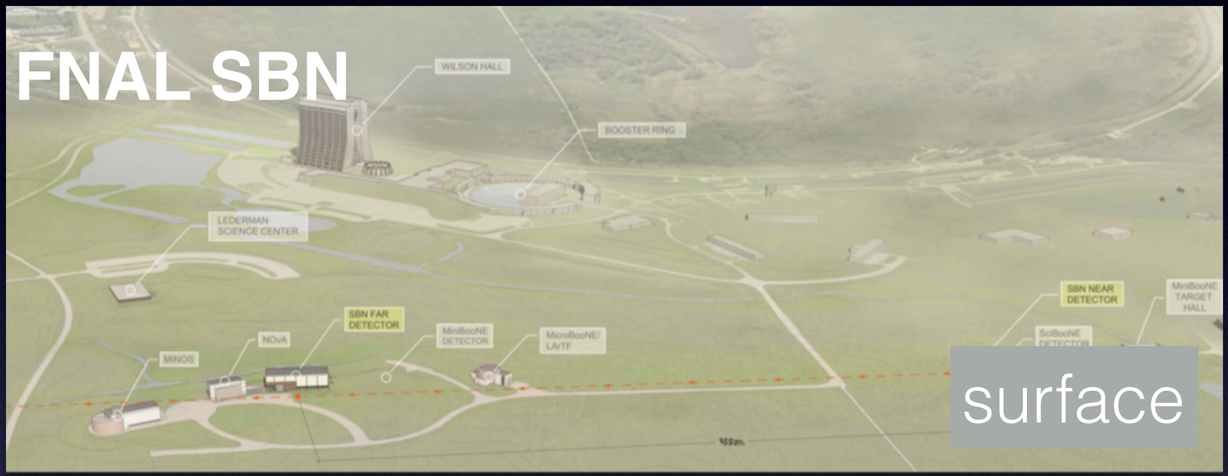

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- conv... ... of sterile ...

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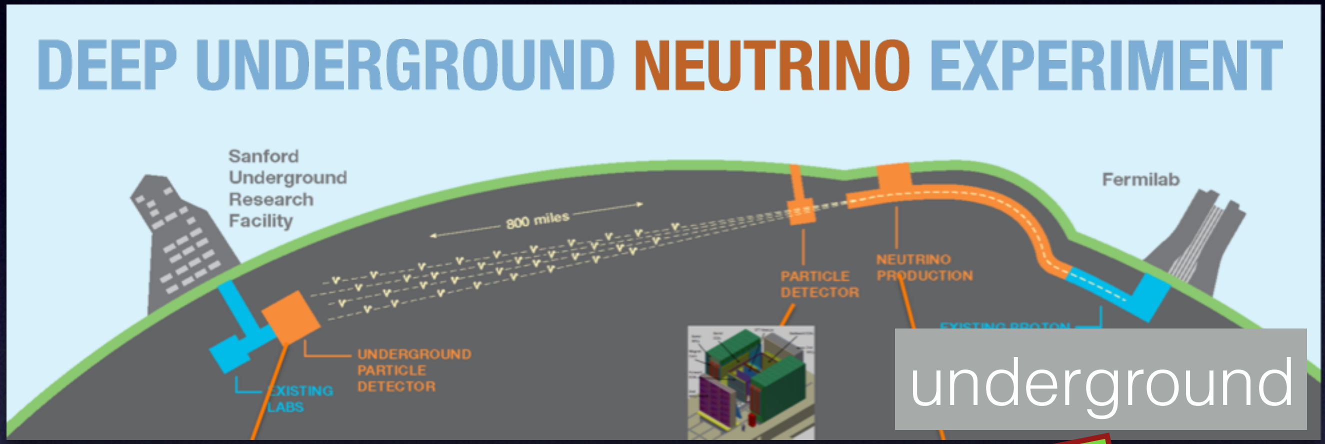

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- the disco... lepton
- ... vation of nucleon
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different phase spaces - exciting physics - major discoveries

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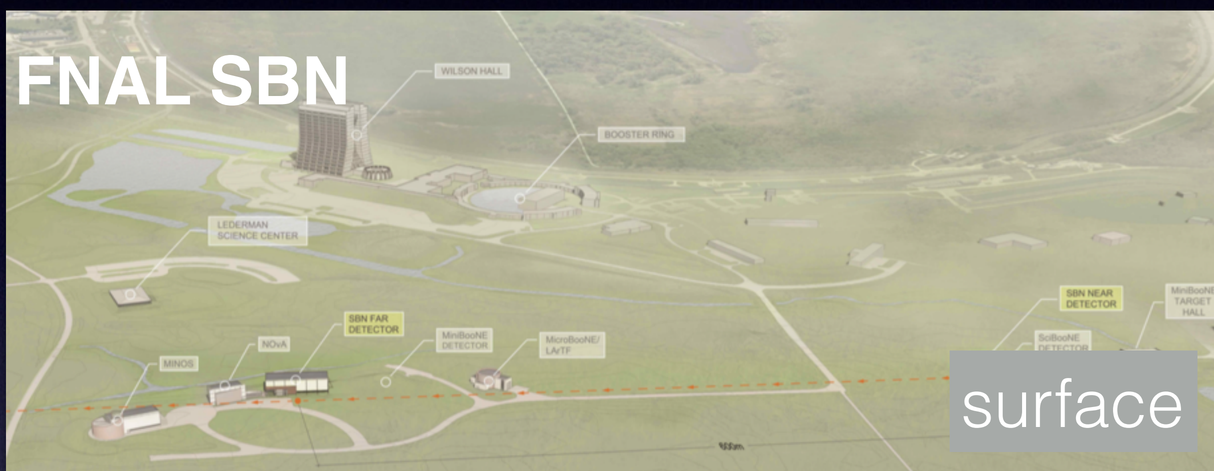

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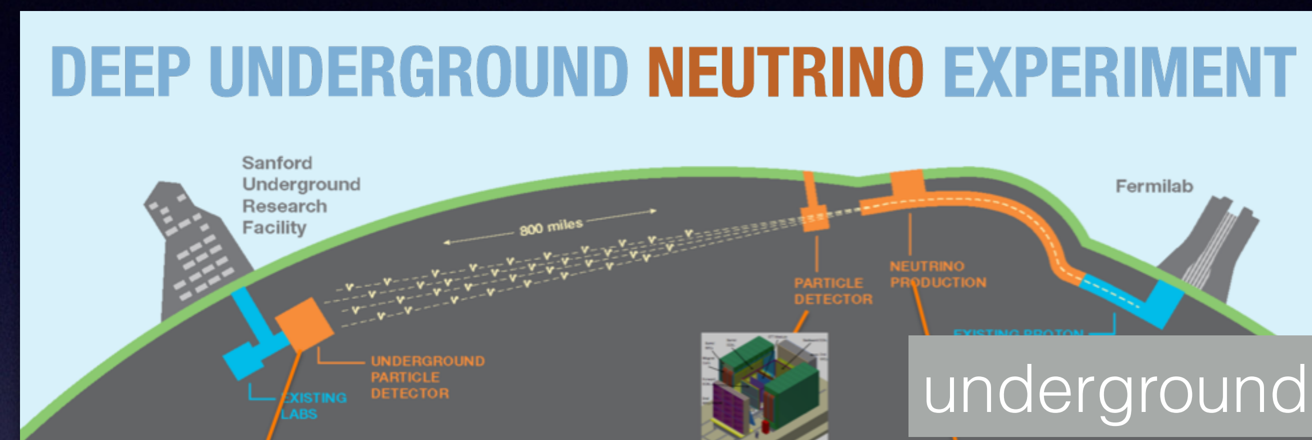

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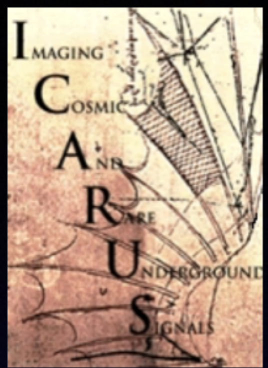
ν_μ -> ν_e appearance experiments
Eν 1-10 GeV

Using the same detector technology to explore those fundamental questions

The technology: It all started 40 year ago



THE LIQUID-ARGON TIME PROJECTION CHAMBER:

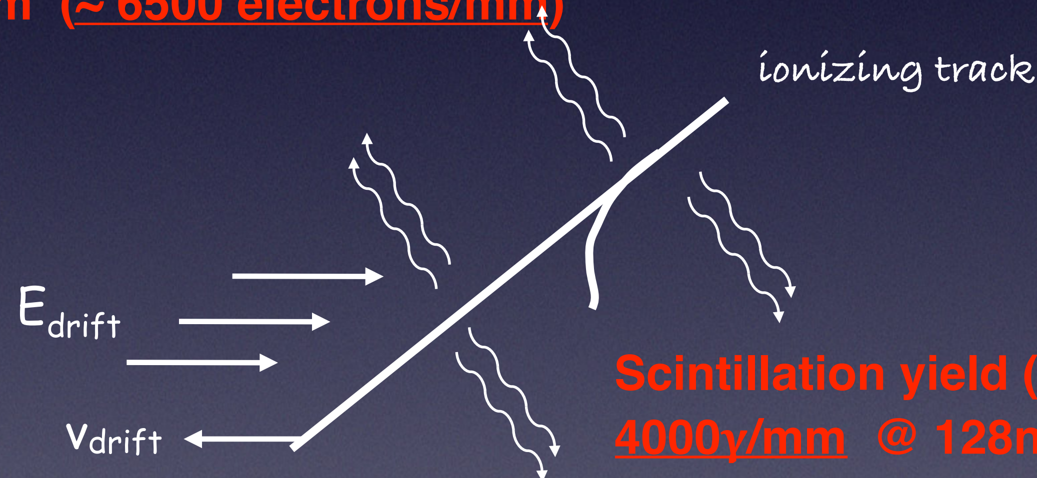
A NEW CONCEPT FOR NEUTRINO DETECTORS

EP Internal Report 77-8

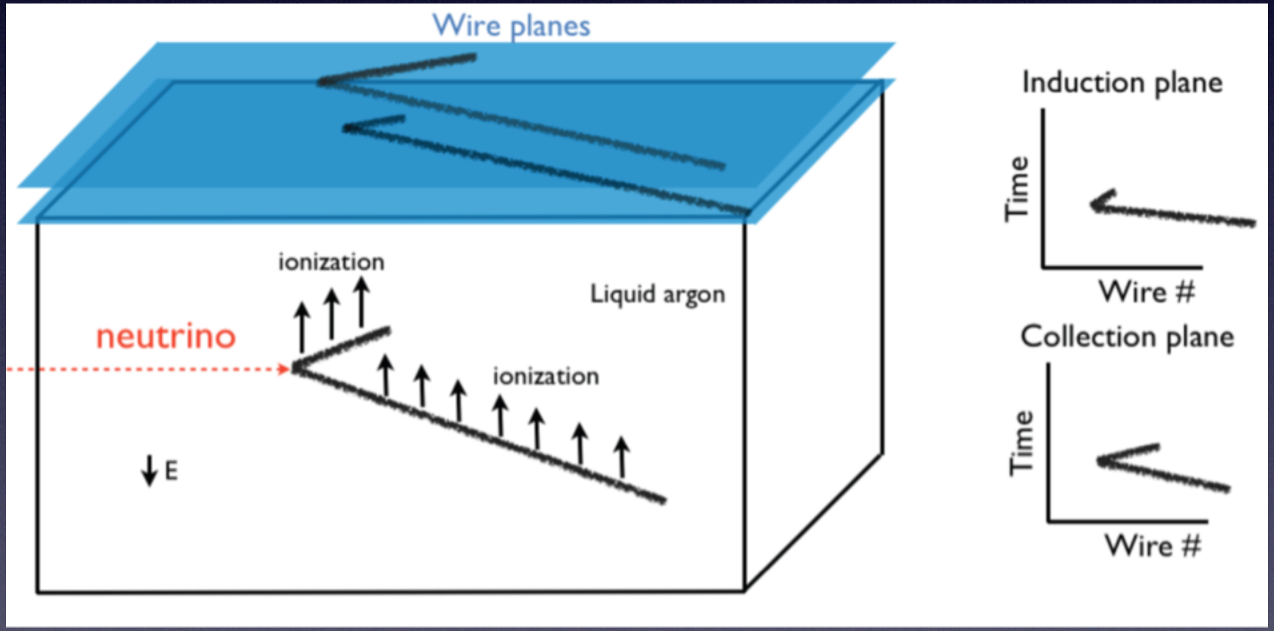
C. Rubbia 16 May 1977

"need for novel device which ***combines*** *the large amount of specific information on the* ***topology of the events of a bubble chamber*** *with the much larger mass, timing, and geometrical flexibility of a* ***counter experiments****"*

Charge yield after e-ion recombination (mip) ~ 1 fC/mm (~ 6500 electrons/mm)

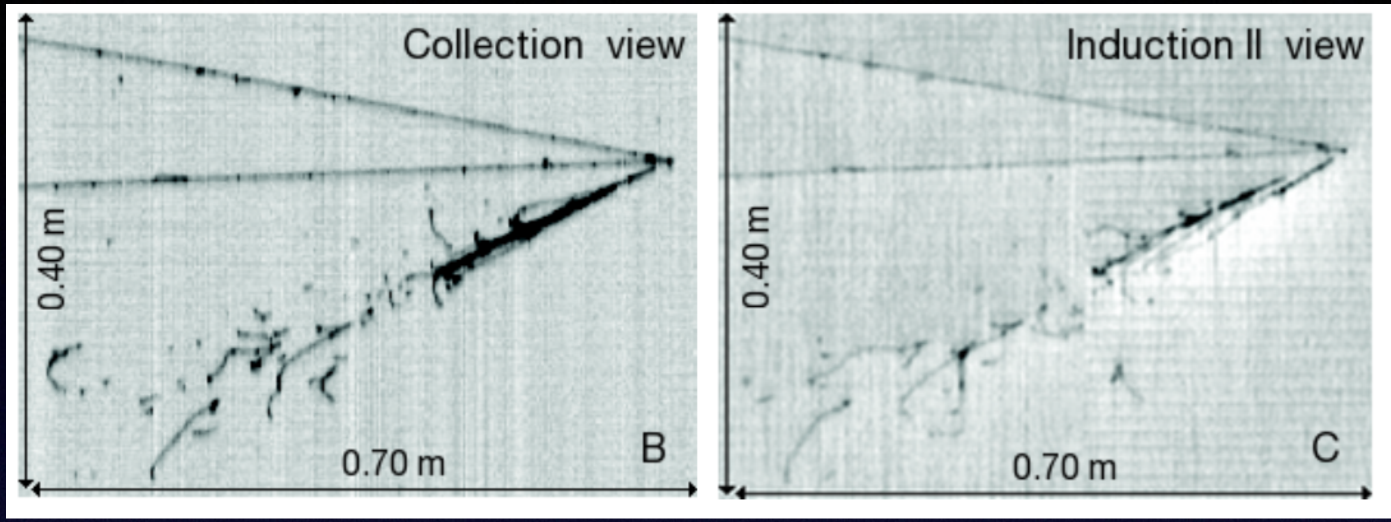


Scintillation yield (mip) ~ 4000γ/mm @ 128nm



The technology: It all started 40 year ago

- **induction view: bi-polar signal induced from the drift electrons.**
- **collection view: unipolar signals.**



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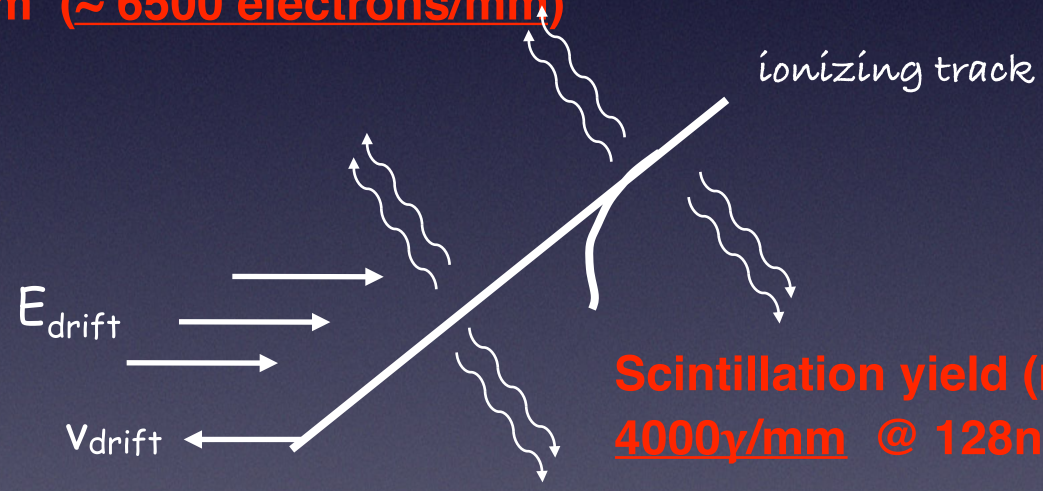

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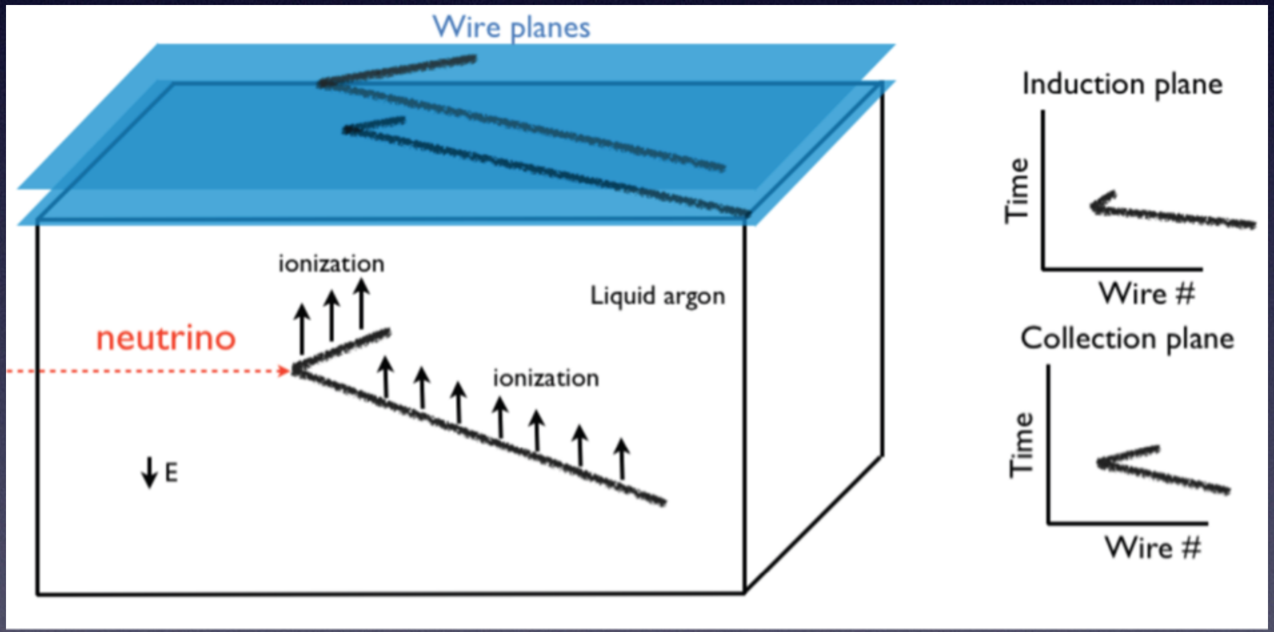
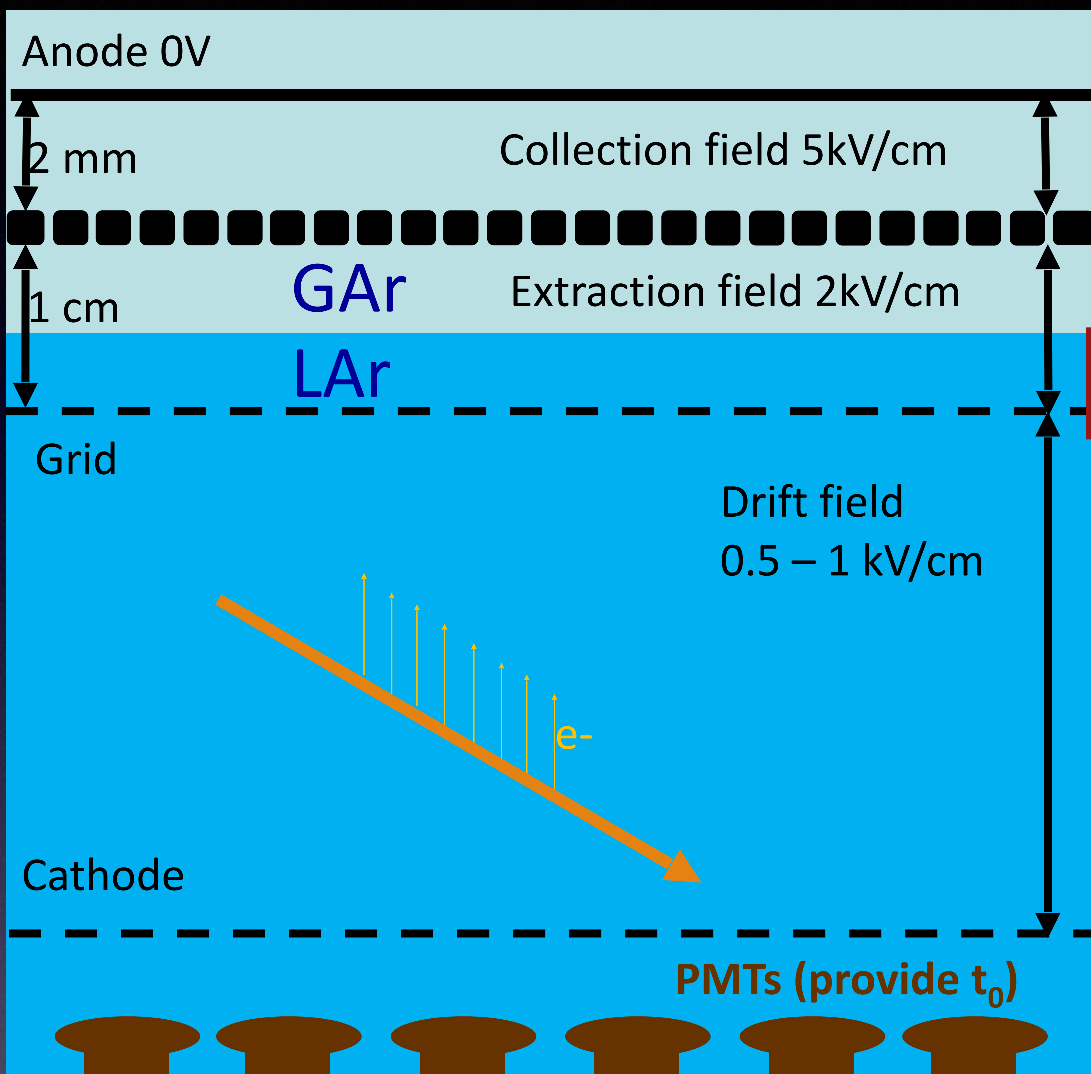
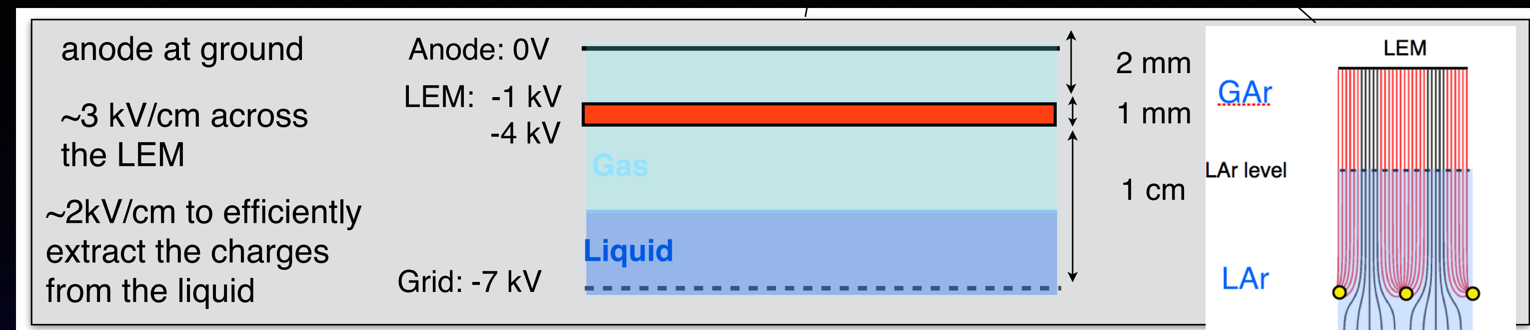


A dense and very fine grained 3D tracking device (mm-scale resolution) with local dE/dx information and a homogenous full sampling calorimeter (e.g. ≈2%X_0 sampling rate for 3mm pitch). It can be operated in trigger-less mode, hence is continuously active.

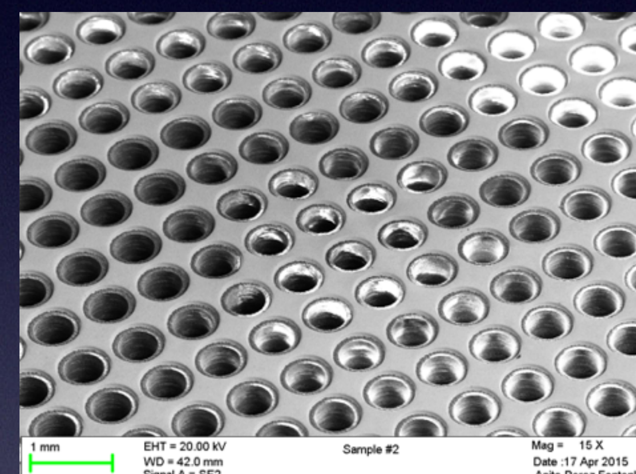
The technology: dual phase

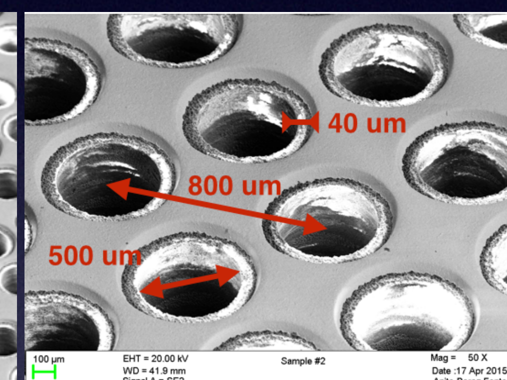
Concept of double-phase LAr TPC (Not to scale)

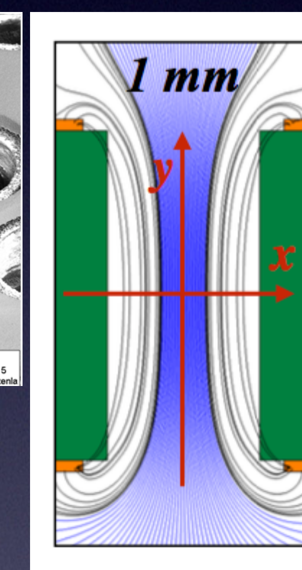




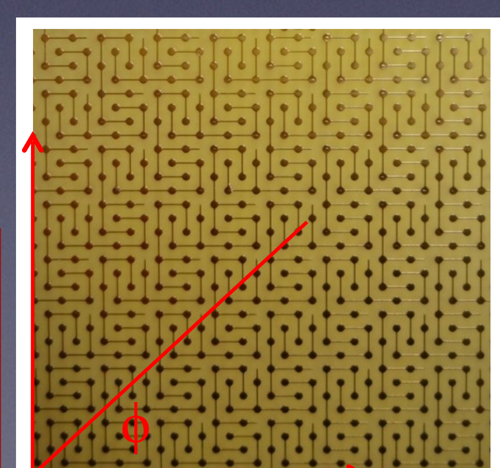
Amplification in LEM holes by Townsend avalanche



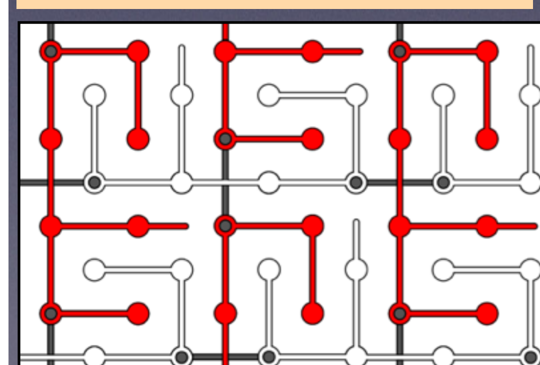


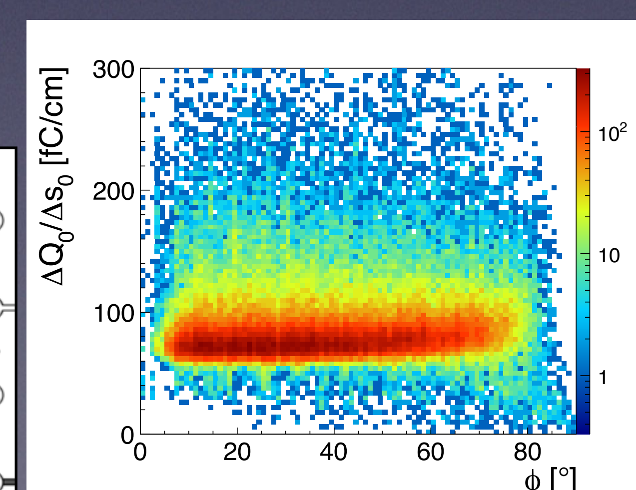


Readout on low capacitance multilayer PCB anodes



dC/dl ~ 120 pF/m

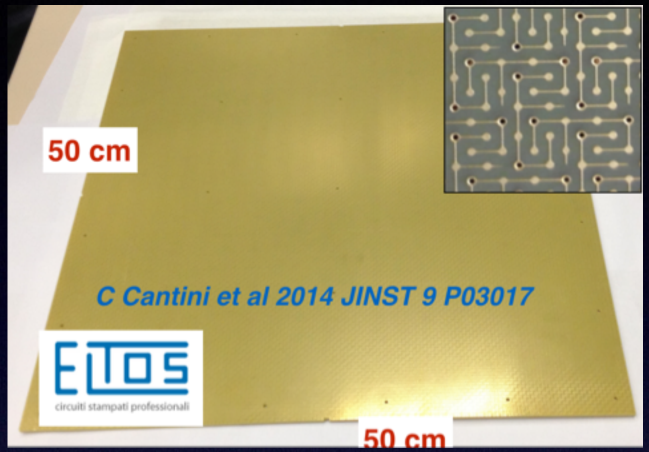


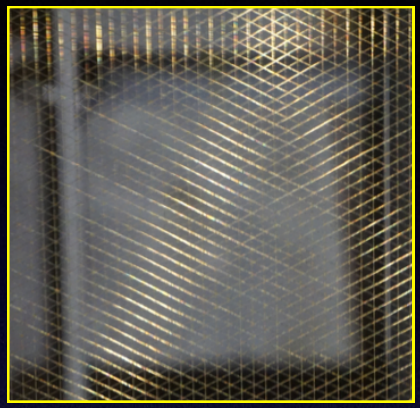


The technology: dual phase

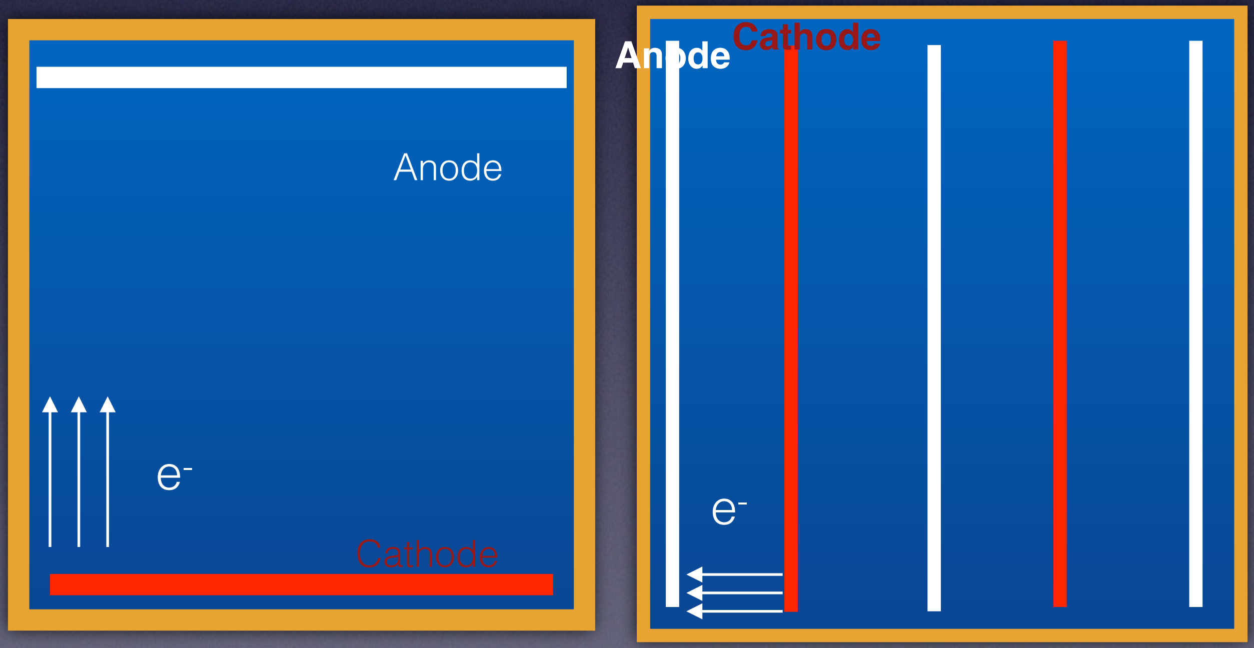
- Double-phase for charge readout with amplification:
  - Long drift distances (>10 meters)
  - More robust S/N ratio with tuneable gain
  - Low energy detection thresholds
  - Gain demonstrated up to 90
  - Optimal gain for neutrino physics operation ≈ 10 - 20
  - readouts with only collection views on PCBs (avoid wire-planes)
  - One fully homogeneous active LAr volume with reduced number of channels.
  - rigid structure insensitive to microphonic noise

PCB anode modules instead of wire planes

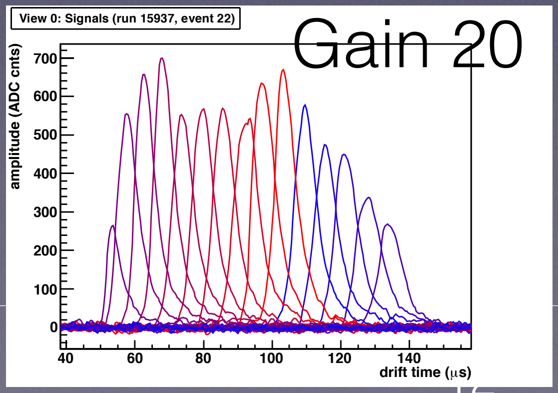




One homogeneous LAr volume instead of multiple A/C

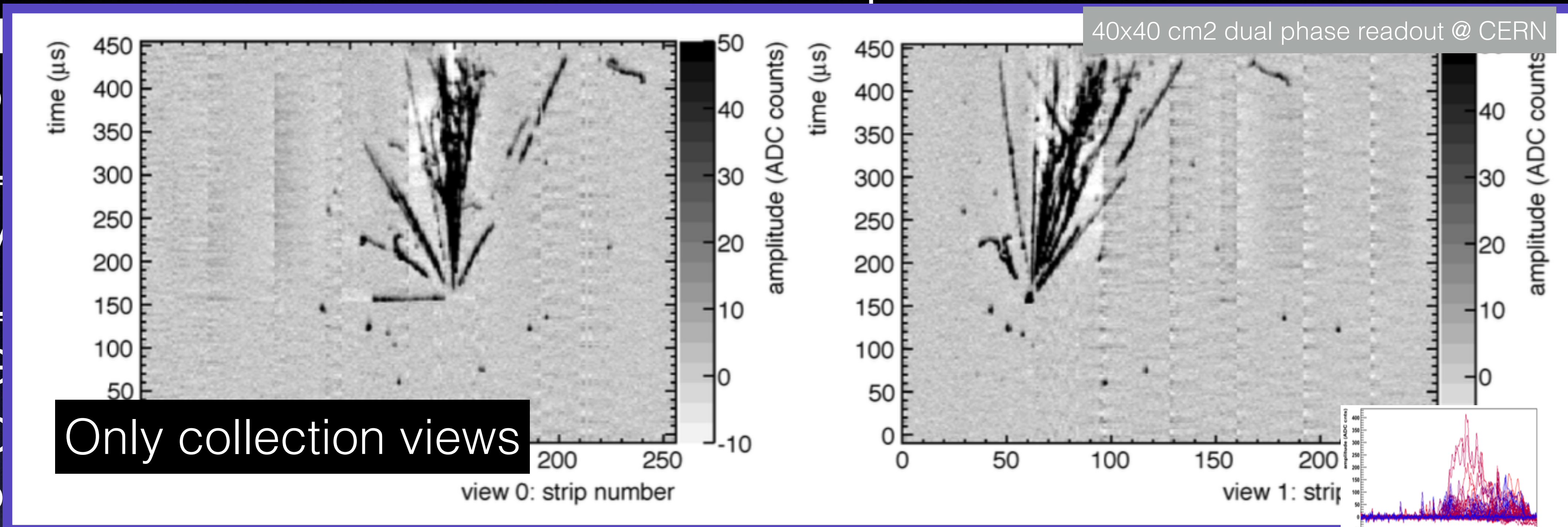


For MIPs:
- 10 fC/cm — ~10 k e^- for each strip (3 mm pitch,2 views) — SNR of 10 (noise of 1000 e^-)
- SNR of 100 — gain of 20 is needed

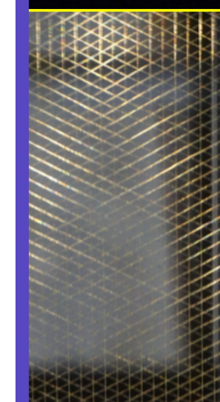


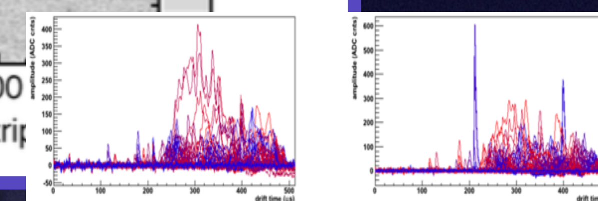
The technology: dual phase

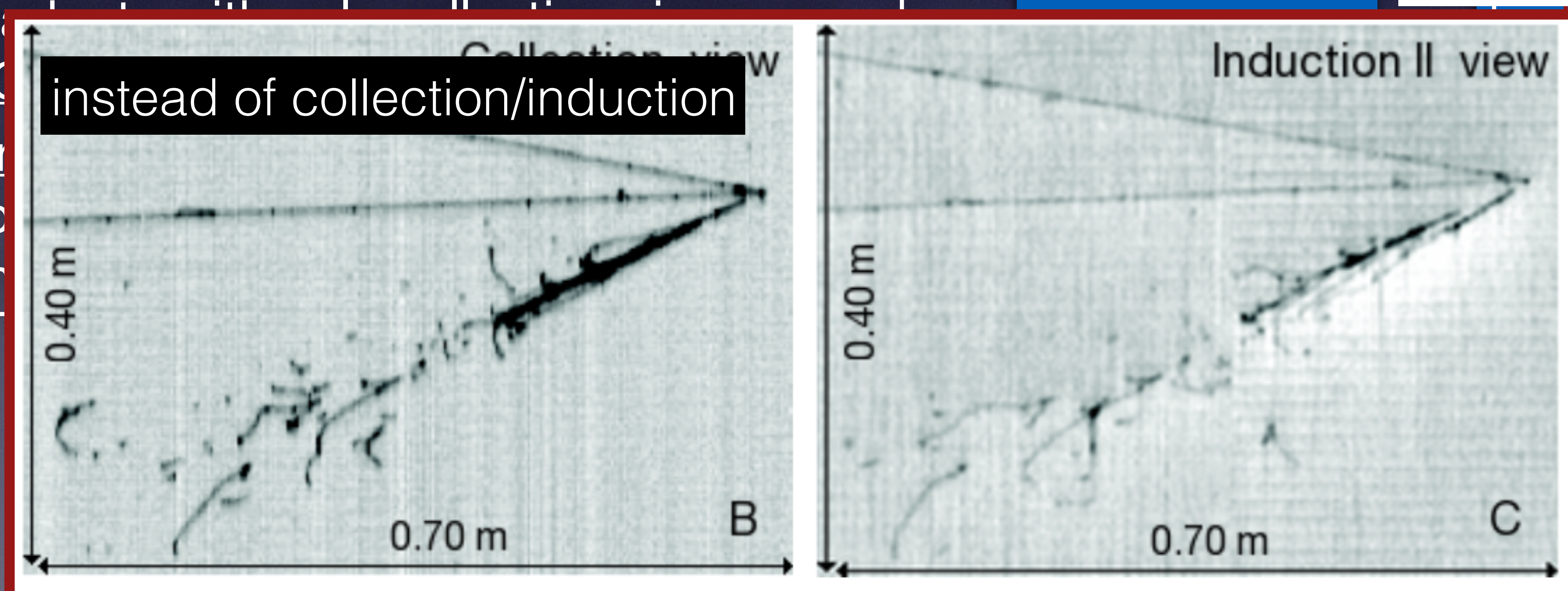
- Doul amp
  - L
  - M
  - L
  - G
  - C o
  - rea PC
  - Or vo ch



Only collection views



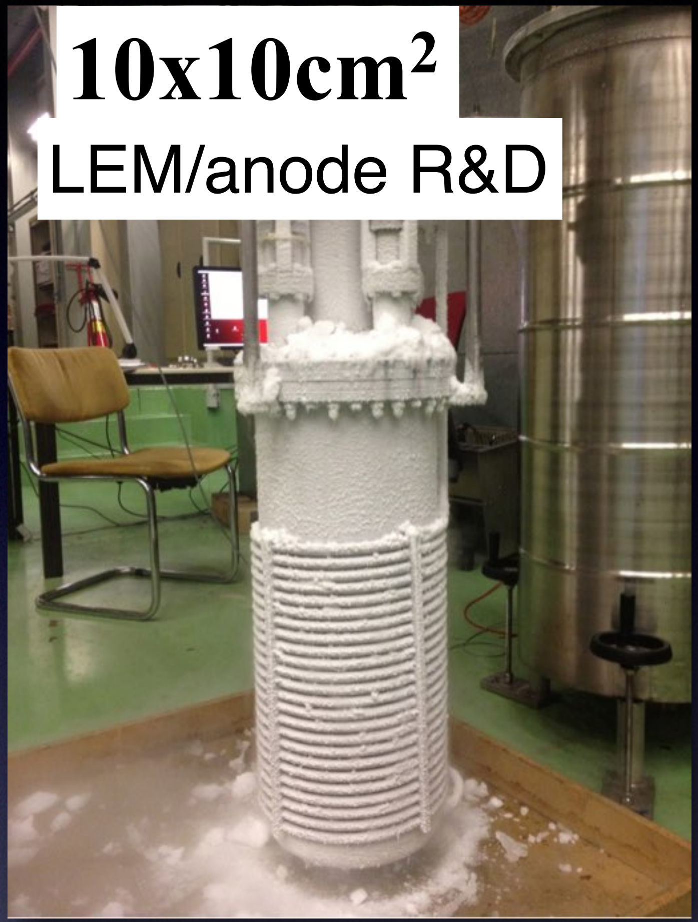


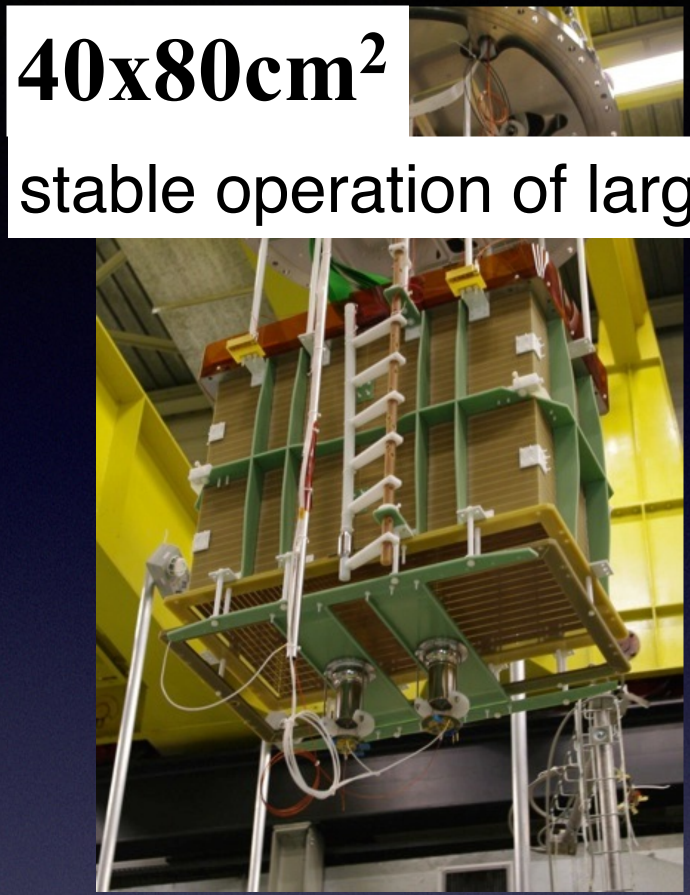


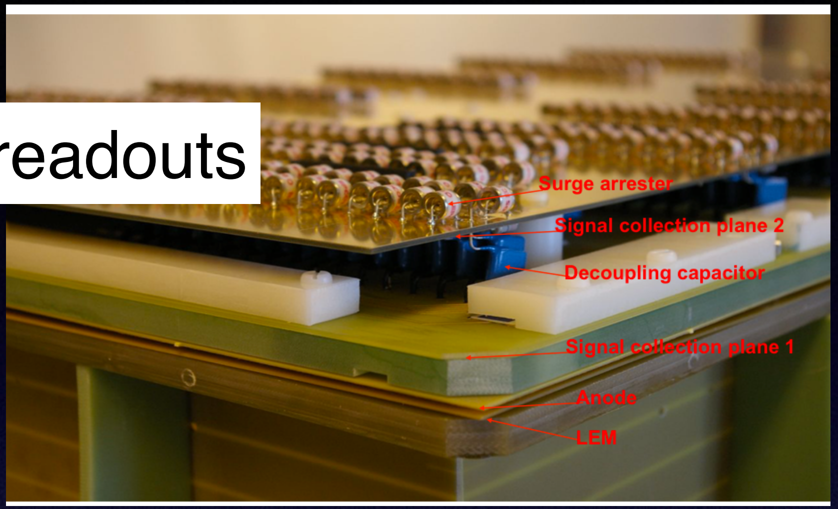
instead of collection/induction

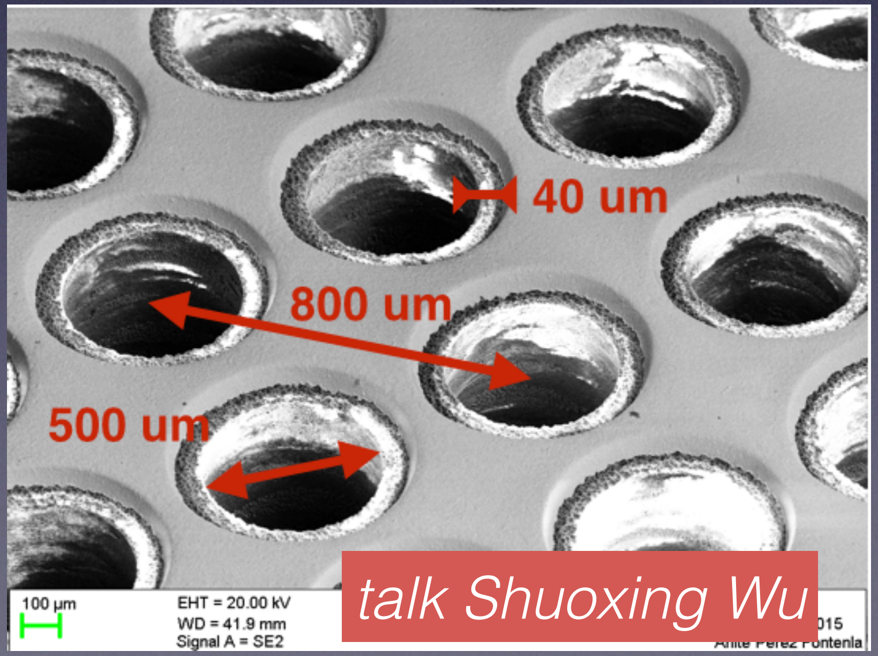
off course scaling up the technology comes with it’s own set off chalenges…

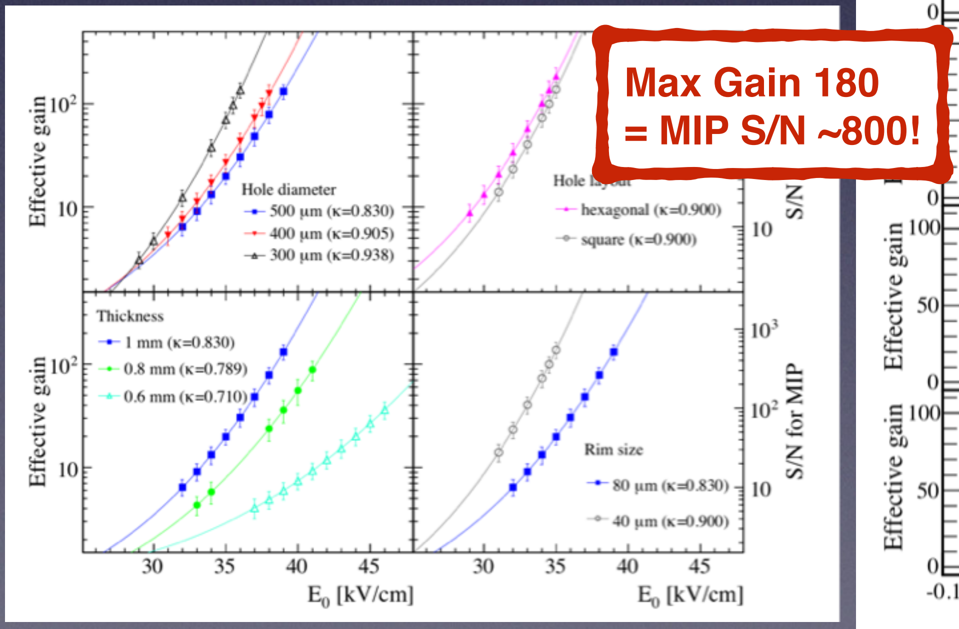
Many years of R&D on small scale prototypes

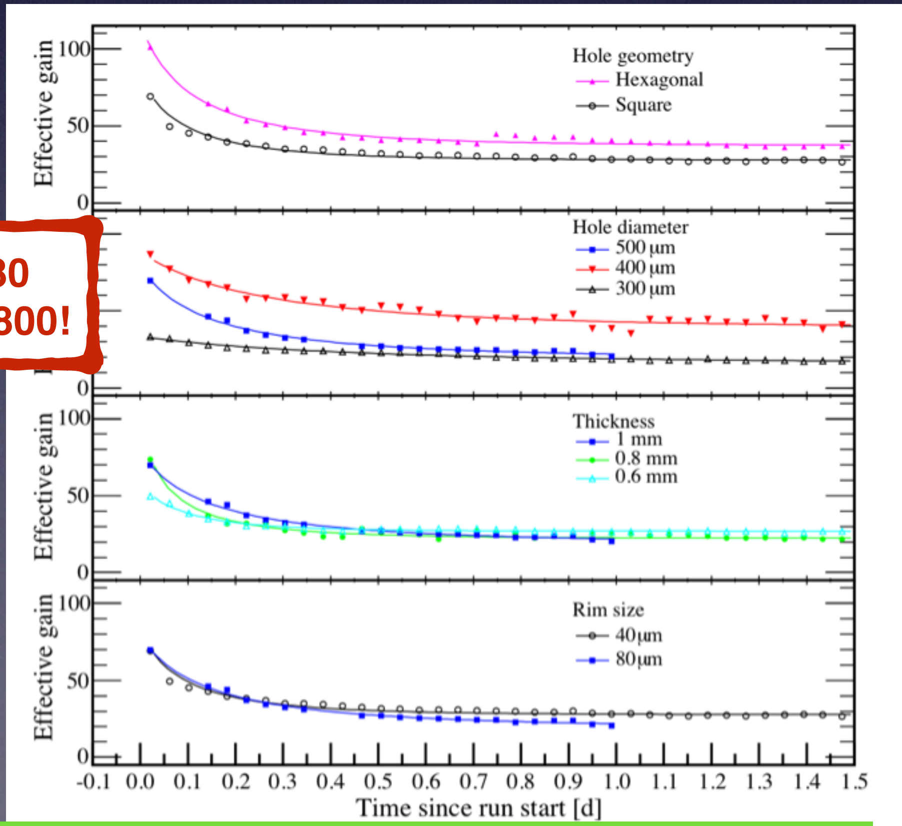






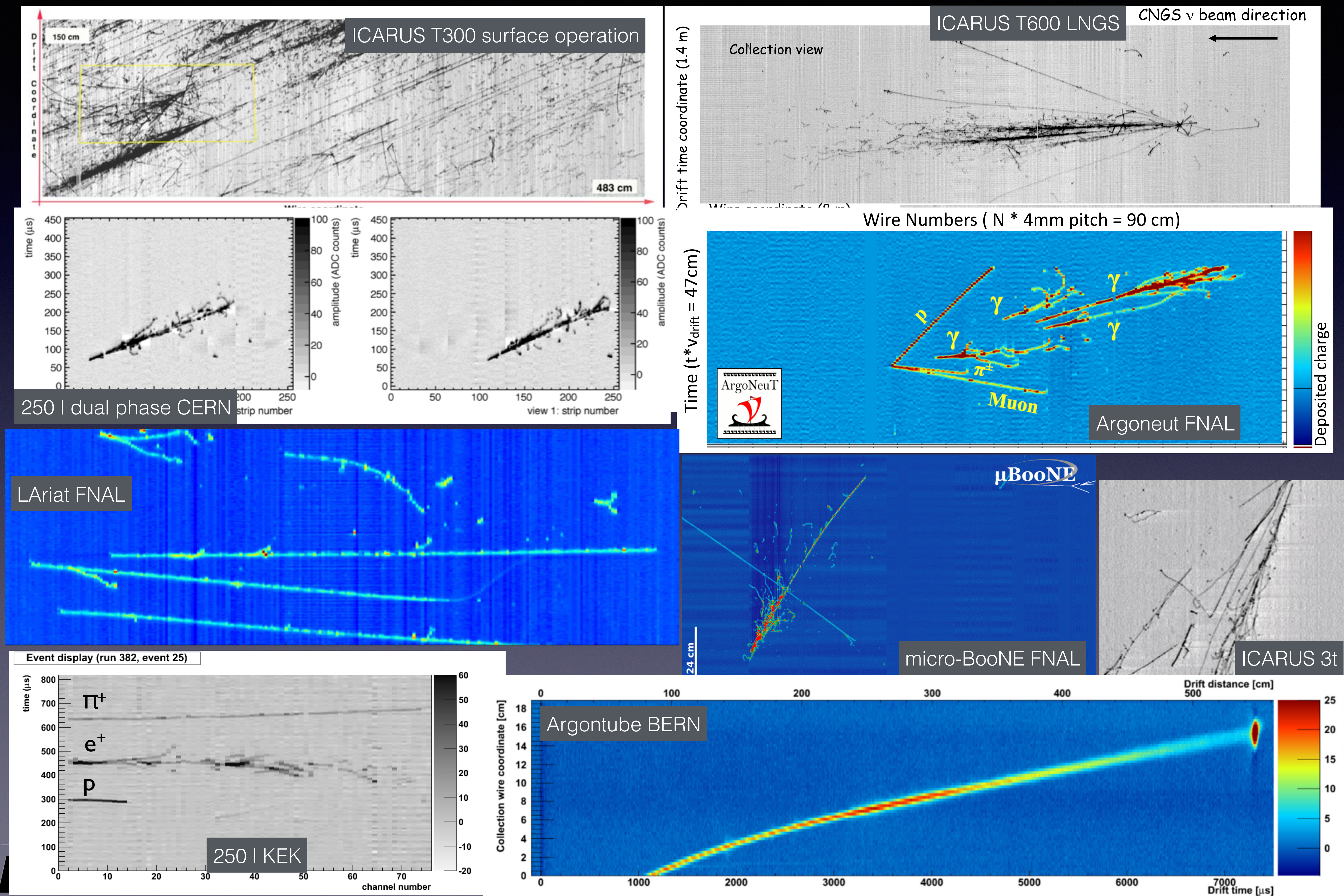




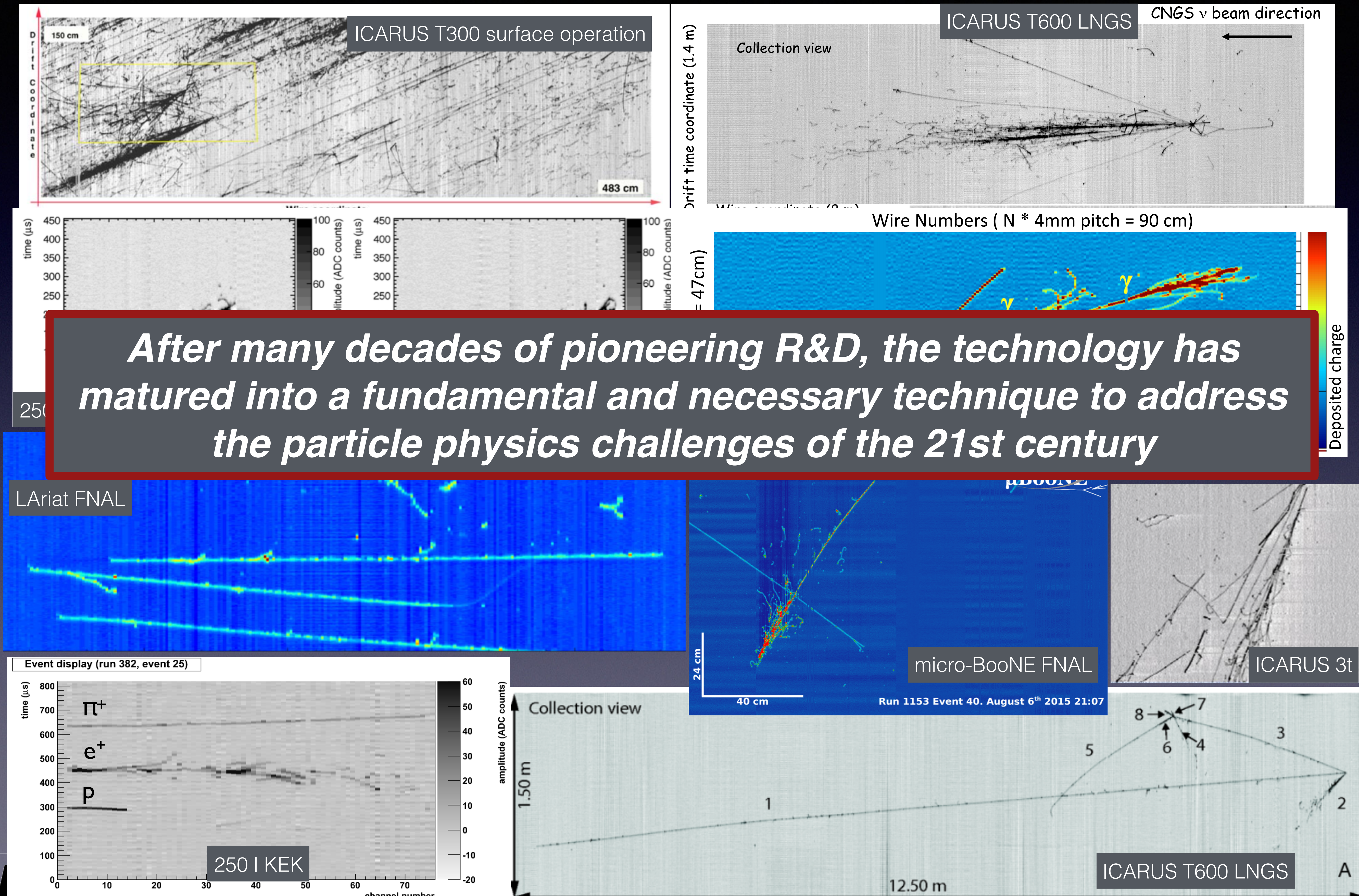


Operating with amplification of about a factor 20

World Wide R&D effort- Event Gallery



World Wide R&D effort- Event Gallery



After many decades of pioneering R&D, the technology has matured into a fundamental and necessary technique to address the particle physics challenges of the 21st century

Near future: the driving experiments

short baseline

<700 MeV> - 600 m - L/E ~1 km/GeV

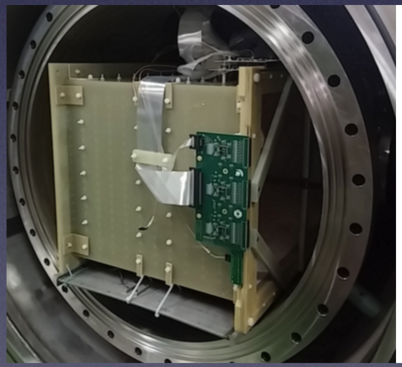
long baseline

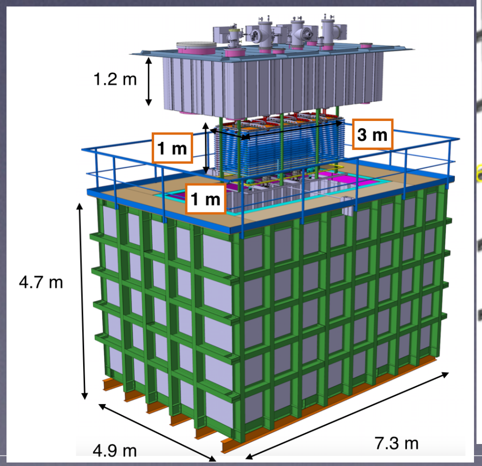
<2 GeV> - 1500 km - L/E ~1000 km/GeV

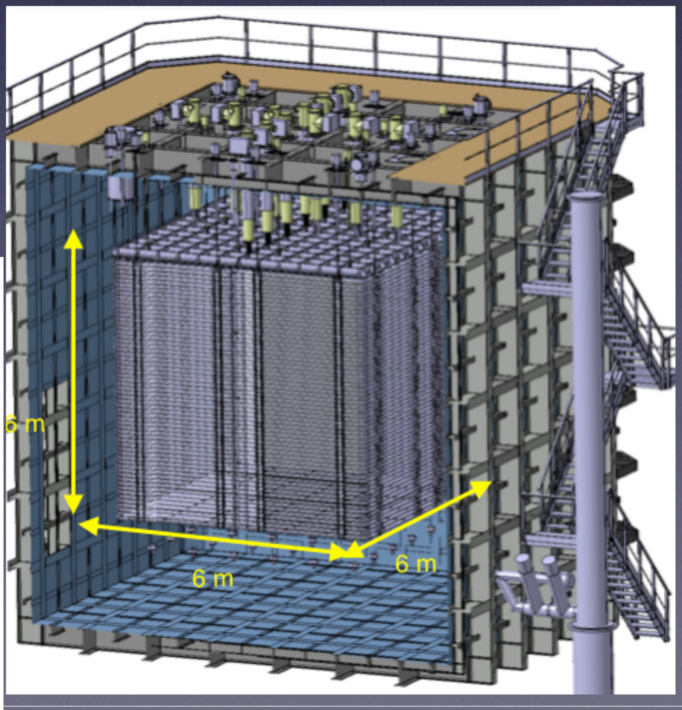
Cross-section measurements in the relevant range for those experiments and keep on gaining experience on the small scale detectors

Large scale detector prototyping.

The indispensable step before going to the multi kt scale.

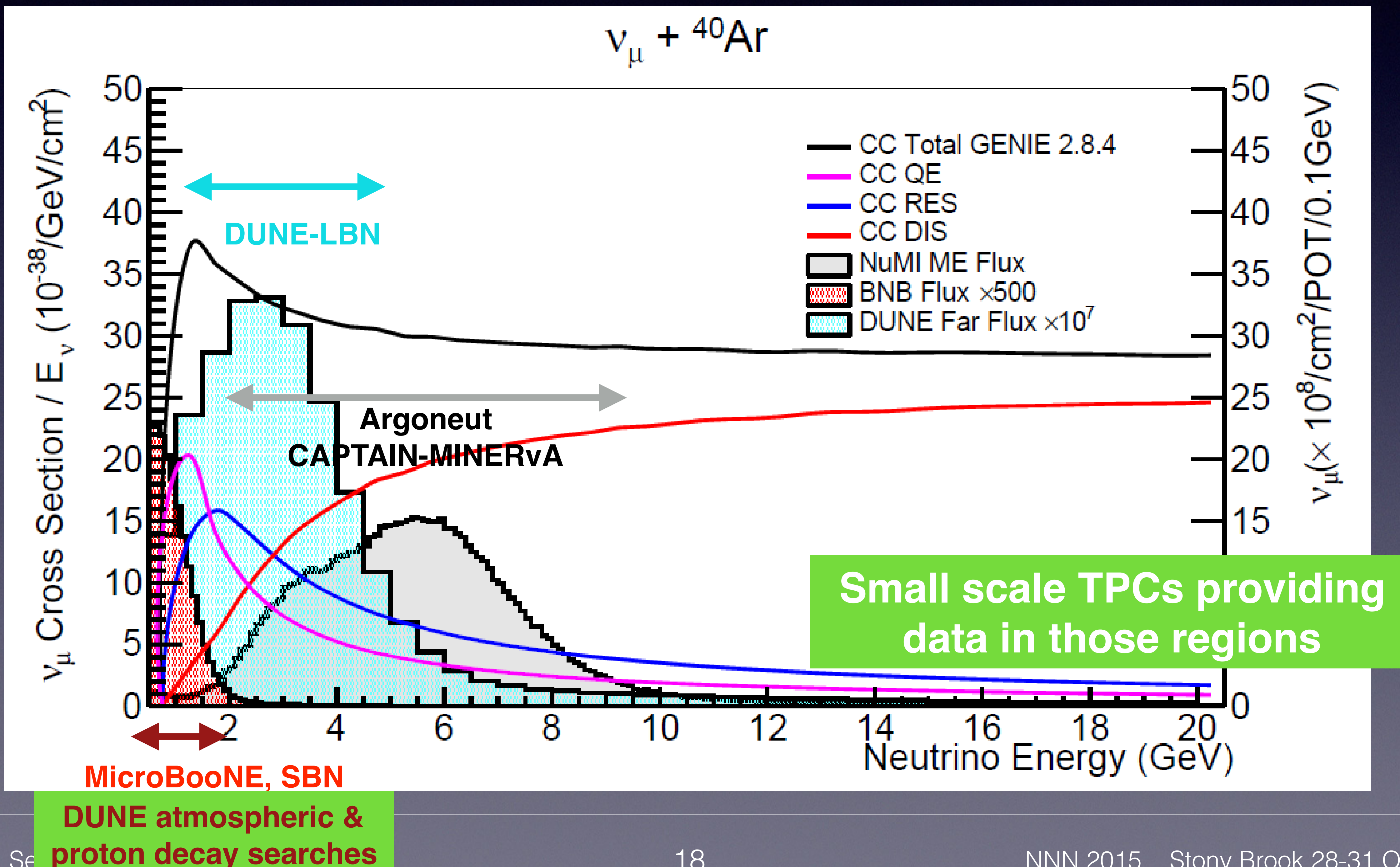





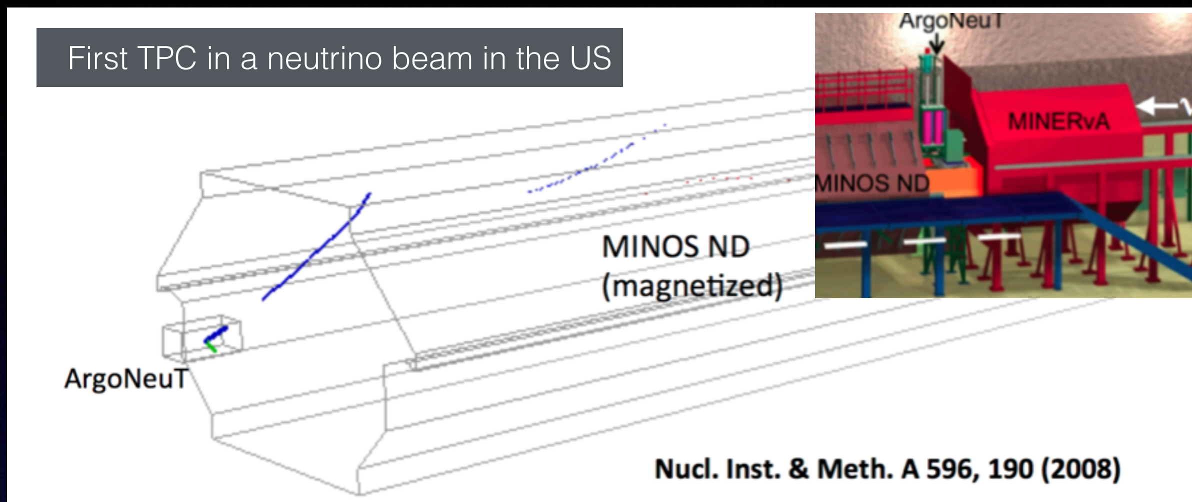
Covering the DUNE/SBN energy range

we want to minimise the need for extrapolations by having a large sample of neutrino-argon data to tune the models.

- There is a clear lack of neutrino-argon data in the neutrino energy range relevant for the short and long-baseline program



ArgoNeuT



- Located in front of MINOS near detector
- **47×40×90 cm3 (170 L),** wire spacing 4 mm
- 2 planes with 480 wires
- Data taking: 9/14/2009 - 2/22/2010
  - 2 weeks in neutrino mode
  - 5 months in anti-neutrino mode

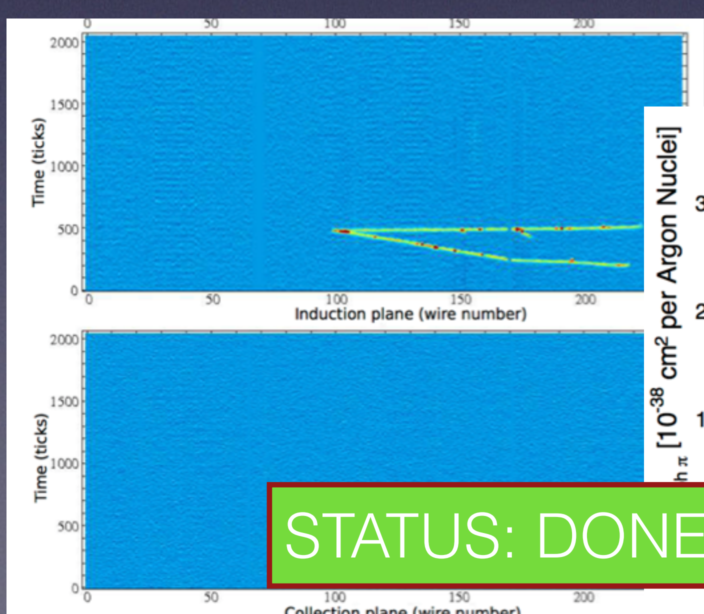
Initially built as small test TPC but yielded extensive physics results

coherent pion production

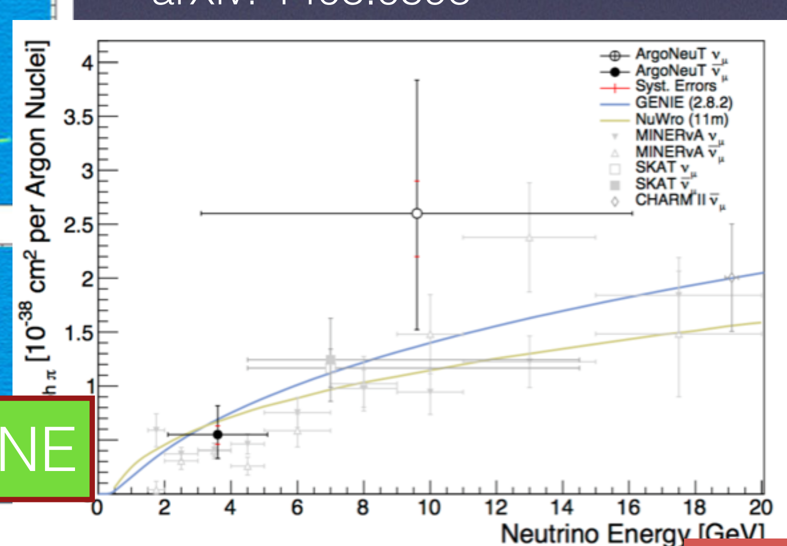
$\nu_\mu + Ar \rightarrow \mu^- + \pi^+ + Ar$

$\bar{\nu}_\mu + Ar \rightarrow \mu^+ + \pi^- + Ar$

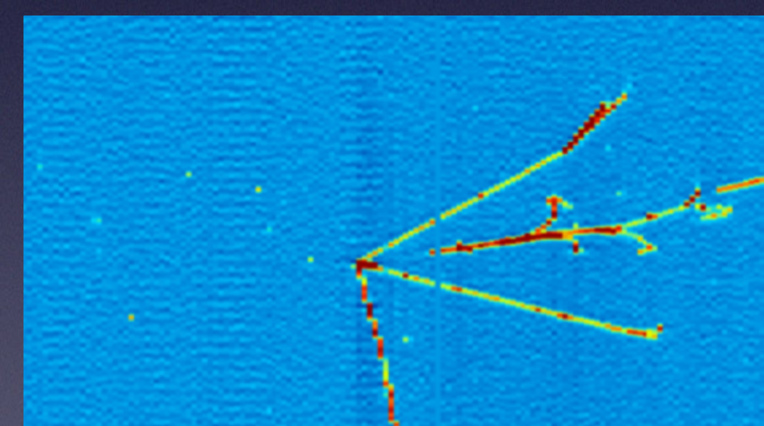
Phys. Rev. Lett. 113, 261801 (2014)
arXiv: 1408.0598



STATUS: DONE

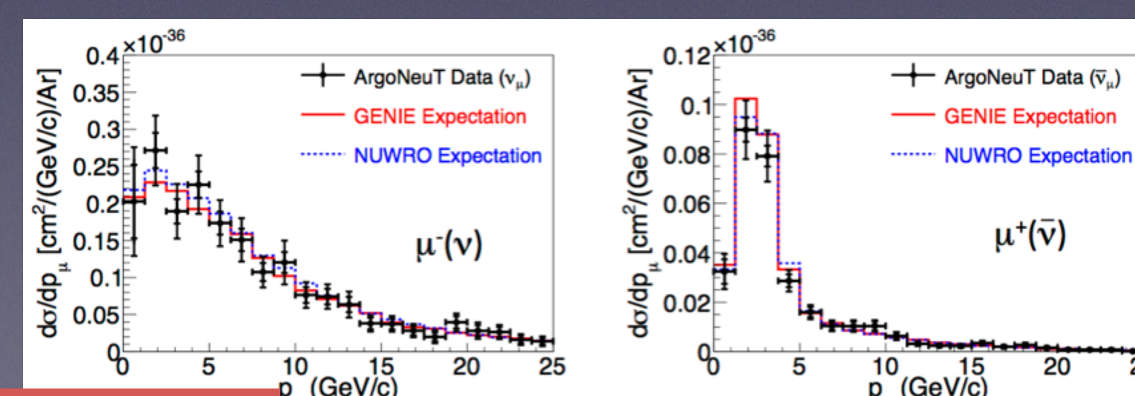


CC inclusive x-sections



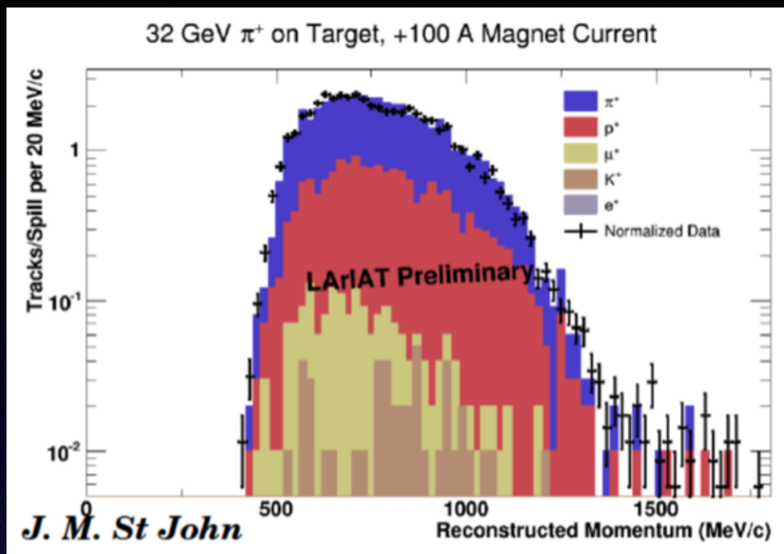
PRD 89 (2014) 112003

1.2e20 POT

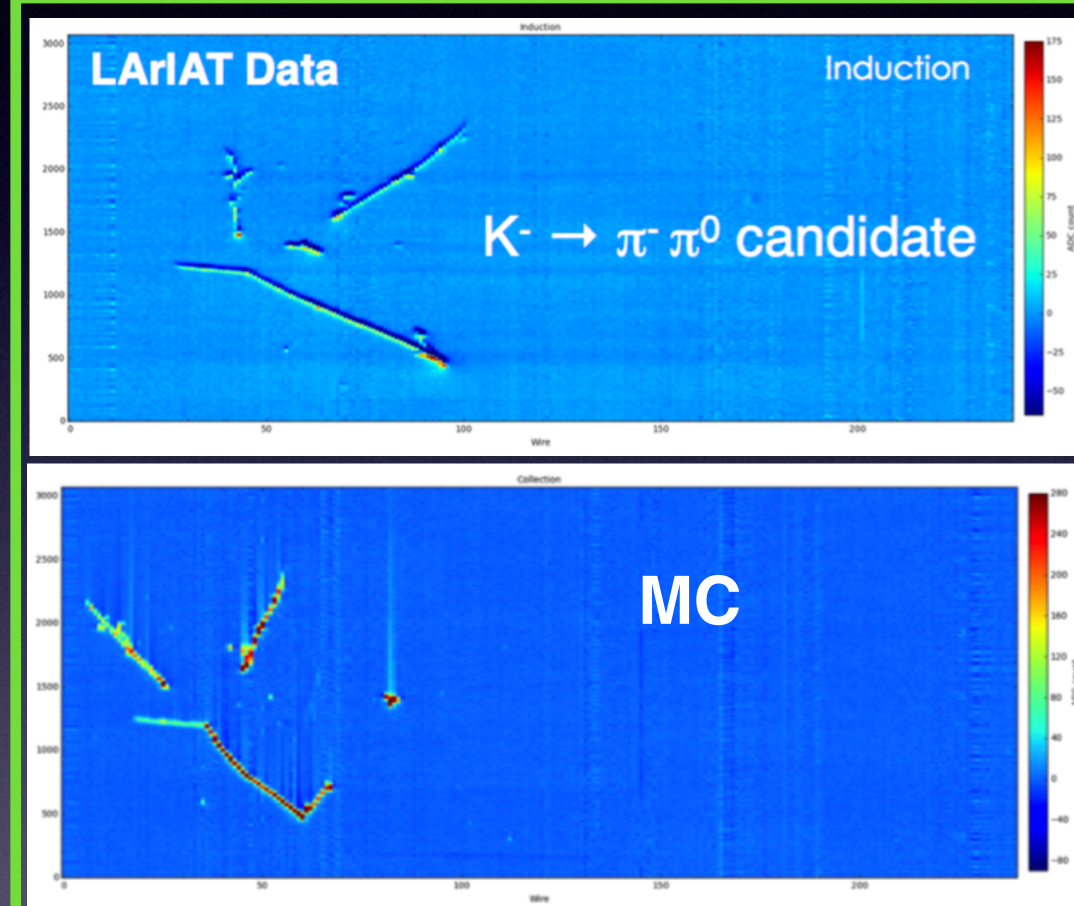


talk Will Flanagan

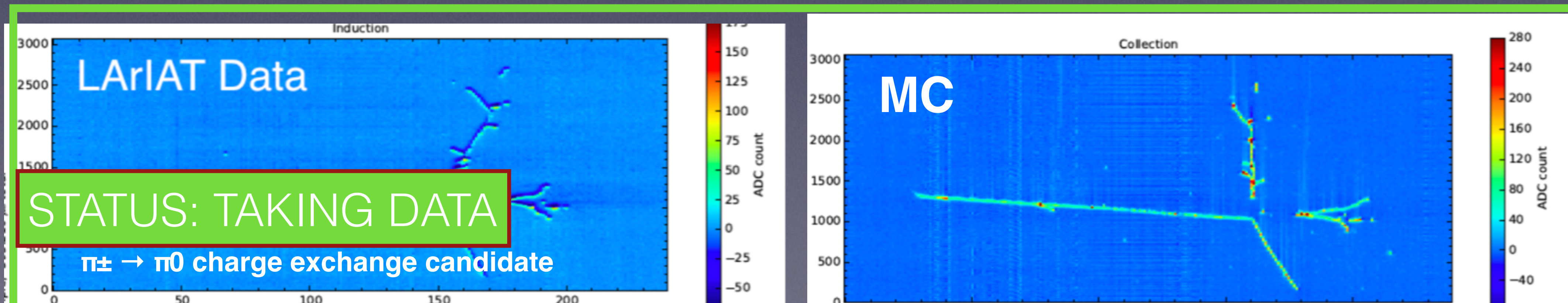
Lariat



Upgrade of ArgoNeuT TPC in a charged particle test beam.



- π-Ar interaction cross sections (total and exclusive channels) Kaon identification (and possibly interaction cross section) e/γ separation
- Muon sign identification via decay vs capture
- Geant4 validation

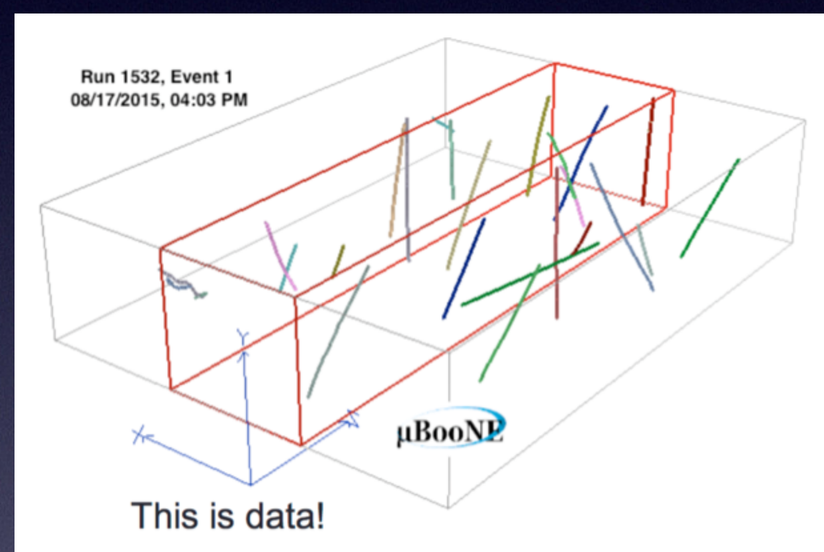


STATUS: TAKING DATA

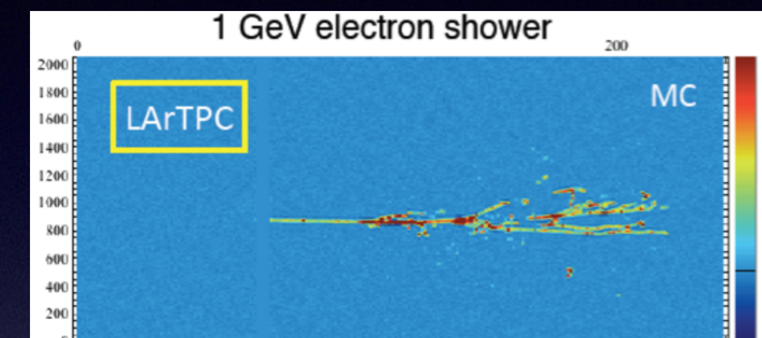
important data to validate and tune Geant4 and Monte Carlo generators.

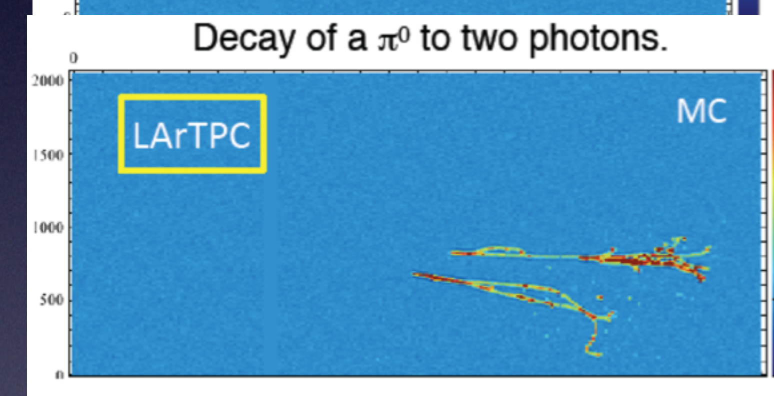
Starting up MicroBooNE

Started this summer. Largest Lar-TPC (90t) operated at Fermilab Lots of experience will be gained (and already has)



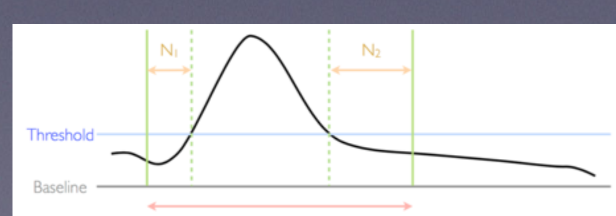
Make use of the excellent e/gamma separation of LAr to provide answers to the low energy signal excess in MinoBooNE and LSND





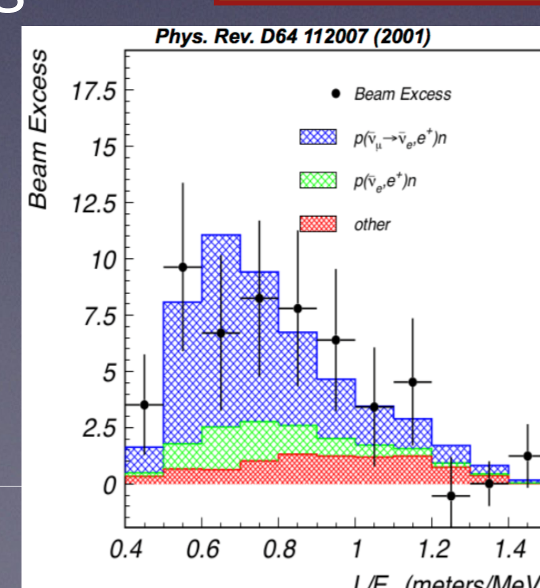
STATUS: TAKING DATA

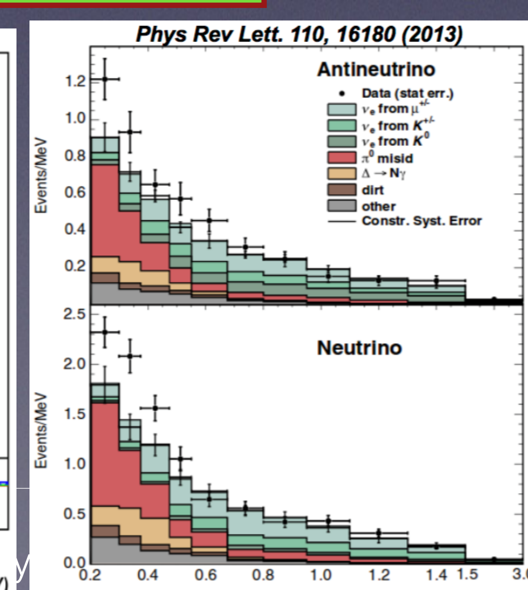
Lots of work ongoing on optimising data transfer.



talk Yun Tse Tsai

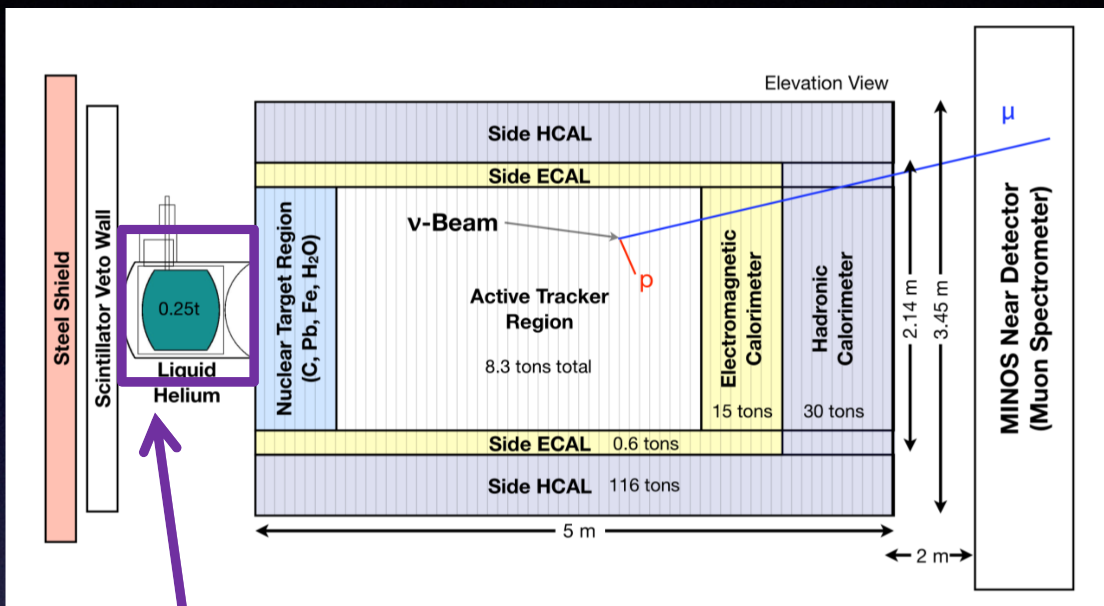
$\nu_s \rightarrow \nu_e$ or $\gamma \rightarrow$ e+e-?

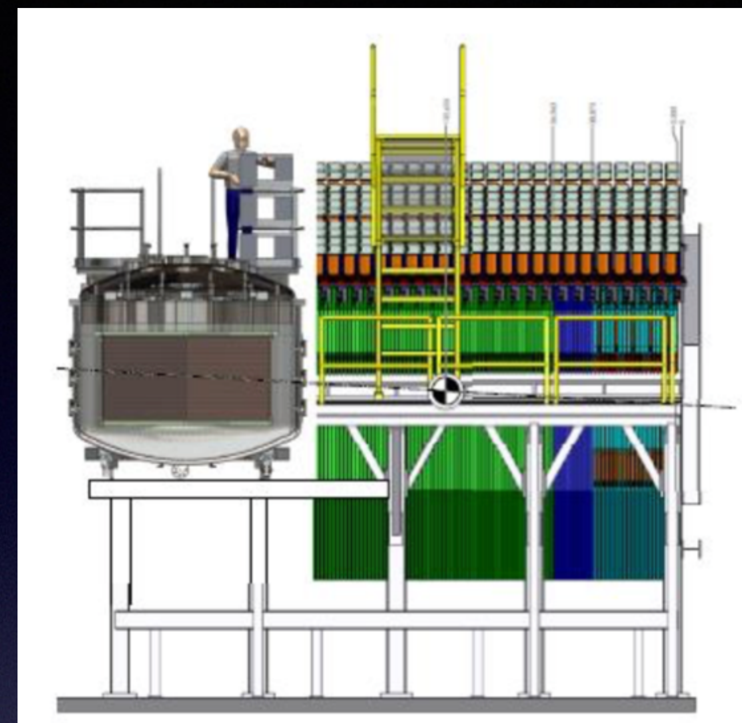


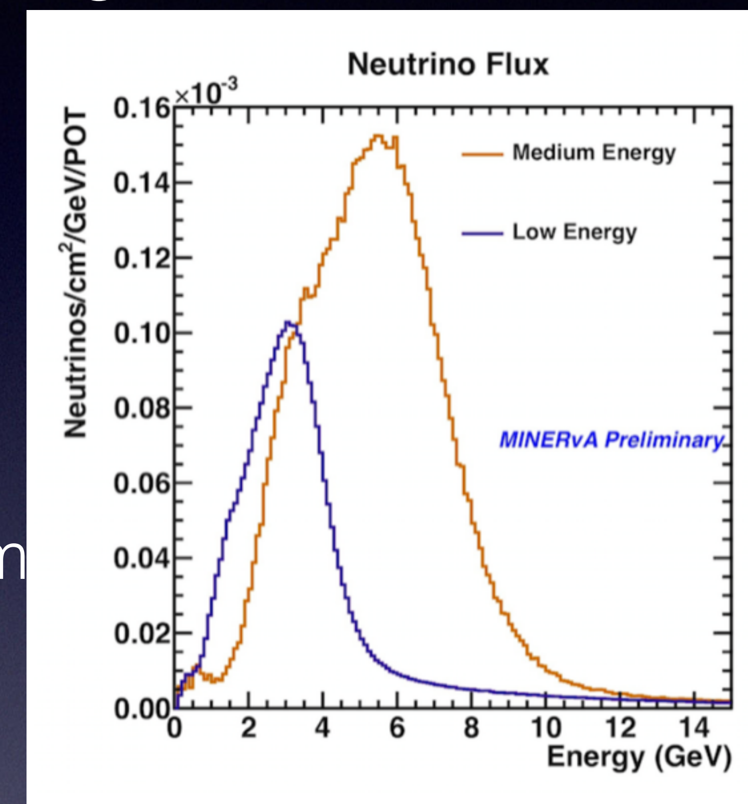


CAPTAIN Minerva

NuMI's medium energy beam covers the 1st oscillation maximum for DUNE







- Neutrino-argon scattering in a medium- energy neutrino beam
- CAPTAIN would serve as the vertex detector, and outgoing particles could be tracked in MINERvA.
- The MINERvA detector can also be used to measure ratios of interactions on argon to other nuclei (remove flux systematic)
- With 20x the fiducial mass than Argoneut a roughly 10x more POT in neutrinos in one year, CAPTAIN will have more statistics and better containment

TIMESCALE: 2018

- Presented LOI to the Fermilab PAC in January 2015
- Presented proposal to Fermilab PAC in June 2015
- Received Stage 1 approval from Fermilab Director in July 2015
- Submitted proposal for funding from DOE's Intermediate Neutrino Research Program ~1 month ago
- The CAPTAIN detector will be commissioned at a surface location at Fermilab beginning in ~2017, with preparations beginning in 2016
- Neutrino data with CAPTAIN-MINERvA beginning in ~2018
- One year ($6x10^{20}$ POT) in neutrino mode + one year in antineutrino mode (contingent on NuMI schedule)

talk Lisa Withehead

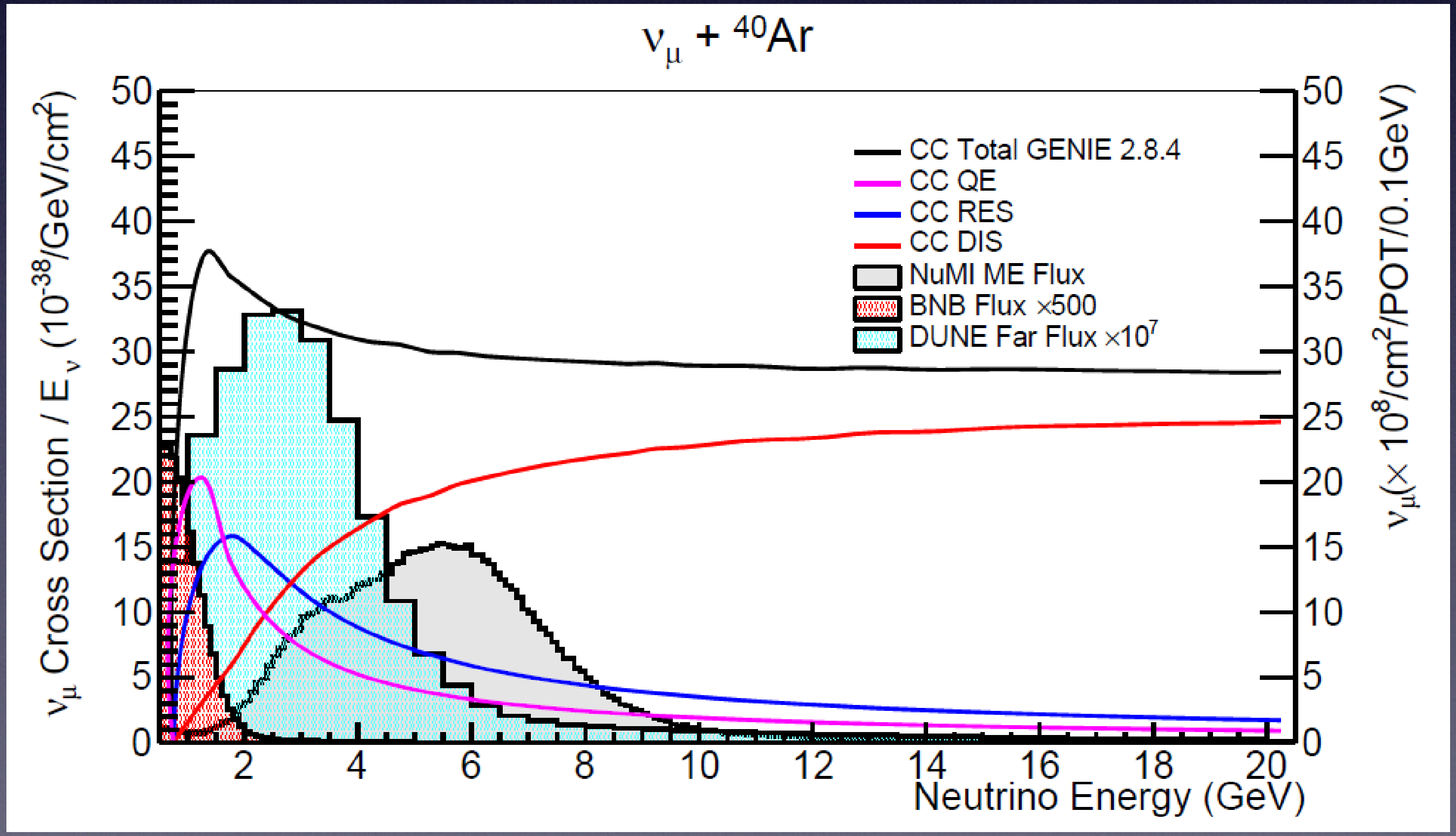
Near future: the driving experiments

short baseline

<700 MeV> - 600 m - L/E ~1 km/GeV

long baseline

<2 GeV> - 1500 km - L/E ~1000 km/GeV



In a few years from now we will have covered large part of the the range of interest. Very exciting measurements ahead!

Near future: the driving experiments

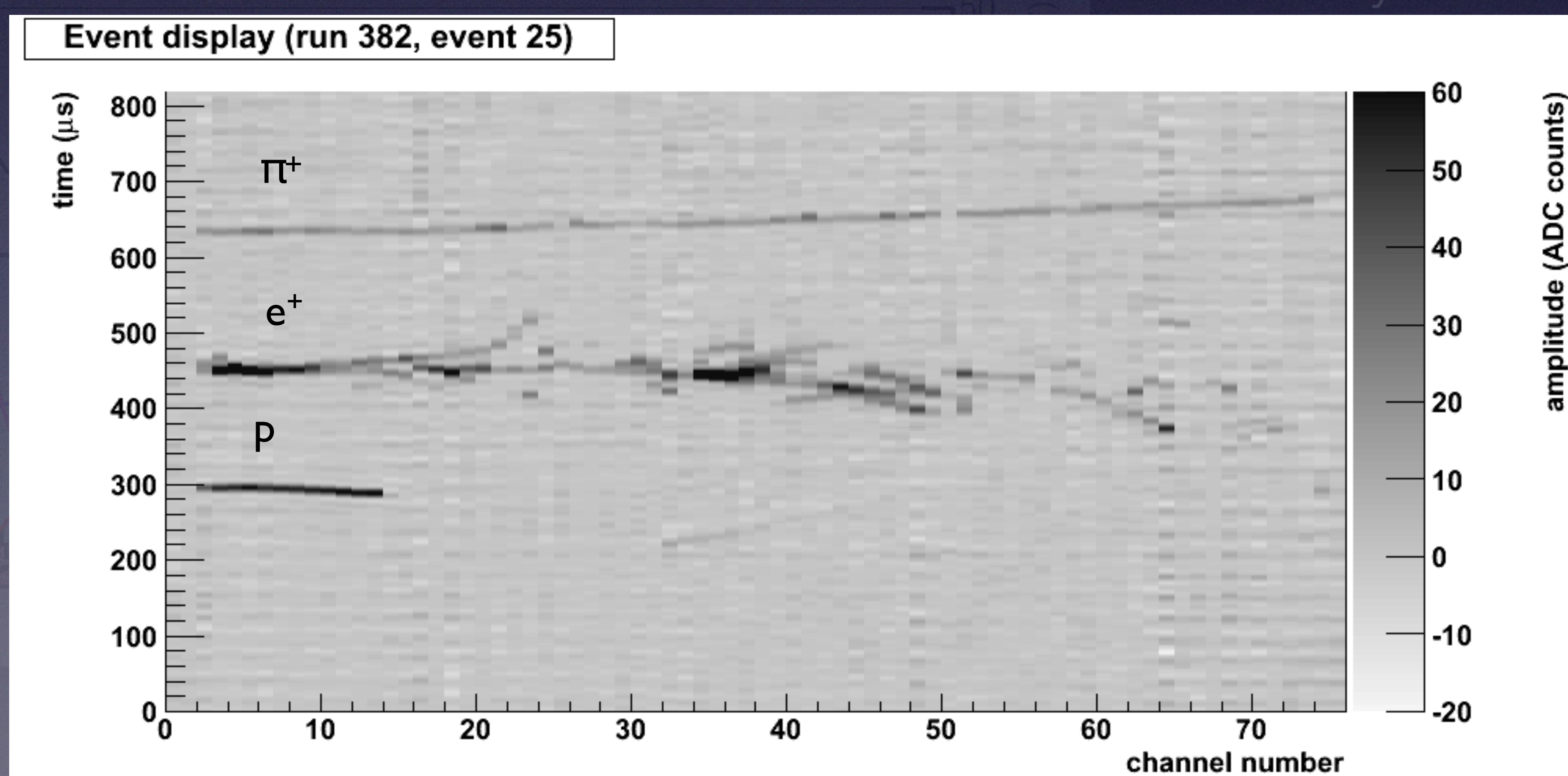
short baseline

<700 MeV> - 600 m - L/E ~1 km/GeV

long baseline

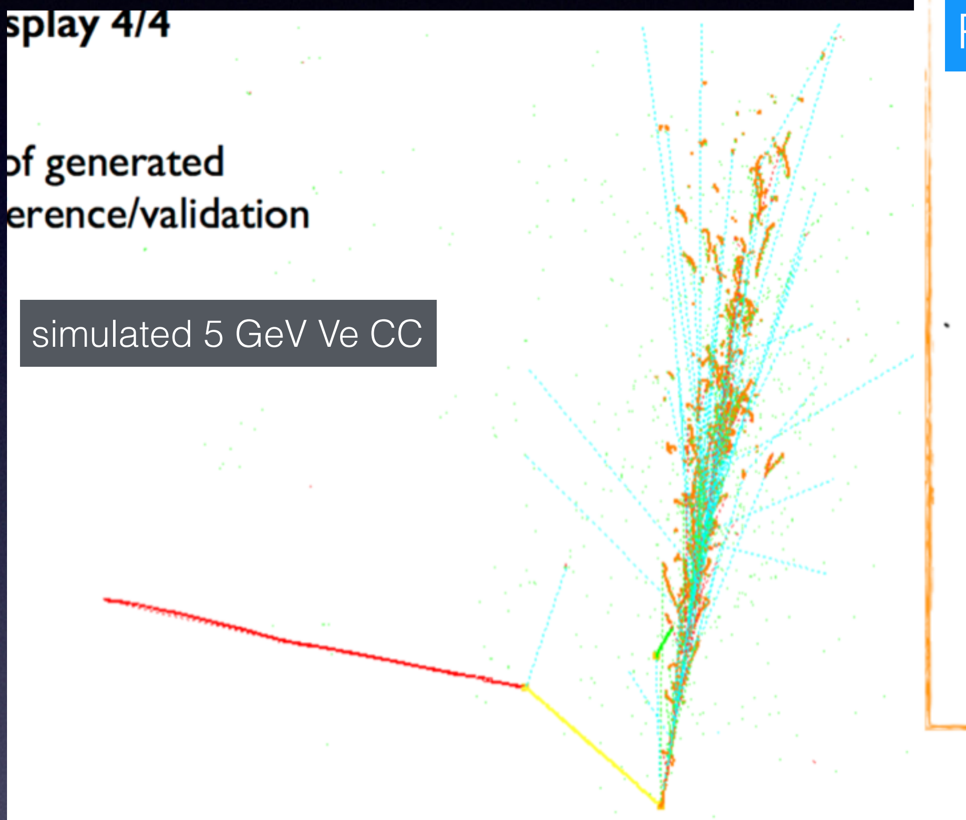
<2 GeV> - 1500 km - L/E ~1000 km/GeV

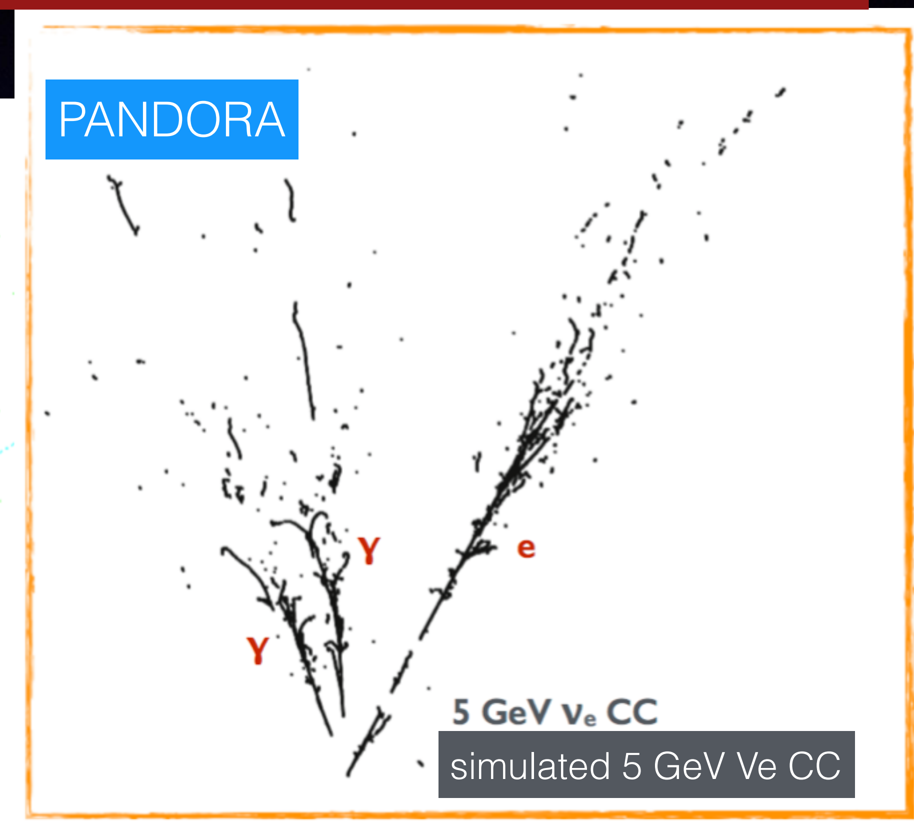
Now the big question:
how do we guarantee such "beautiful events" at the multi-kt scale?

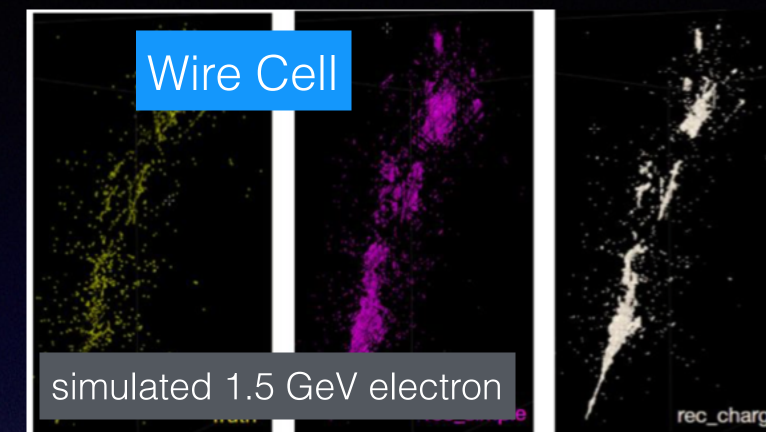


Event reconstruction

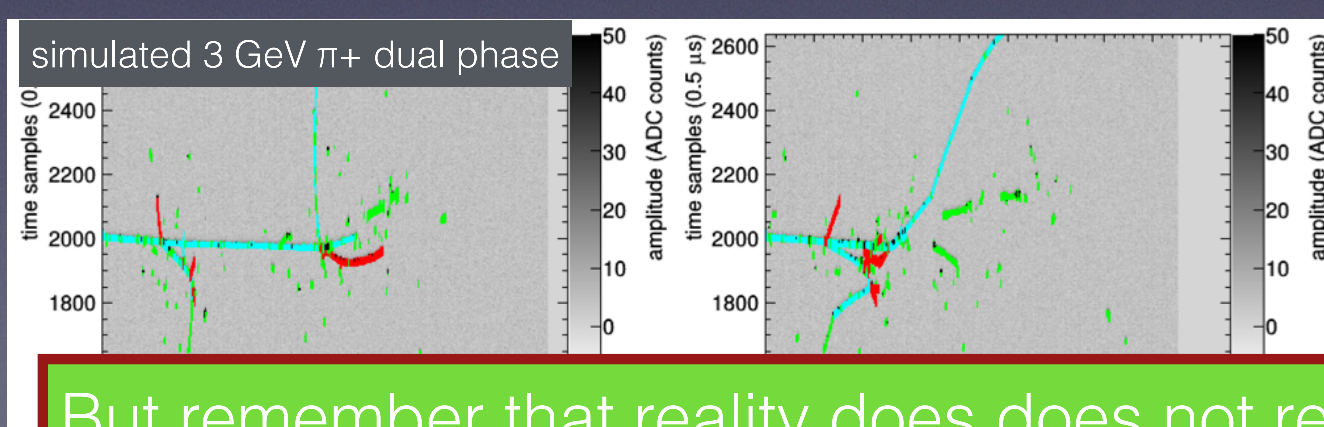
Important (and interesting topic). Lots of ideas that will come together and keep improving as more data arrives

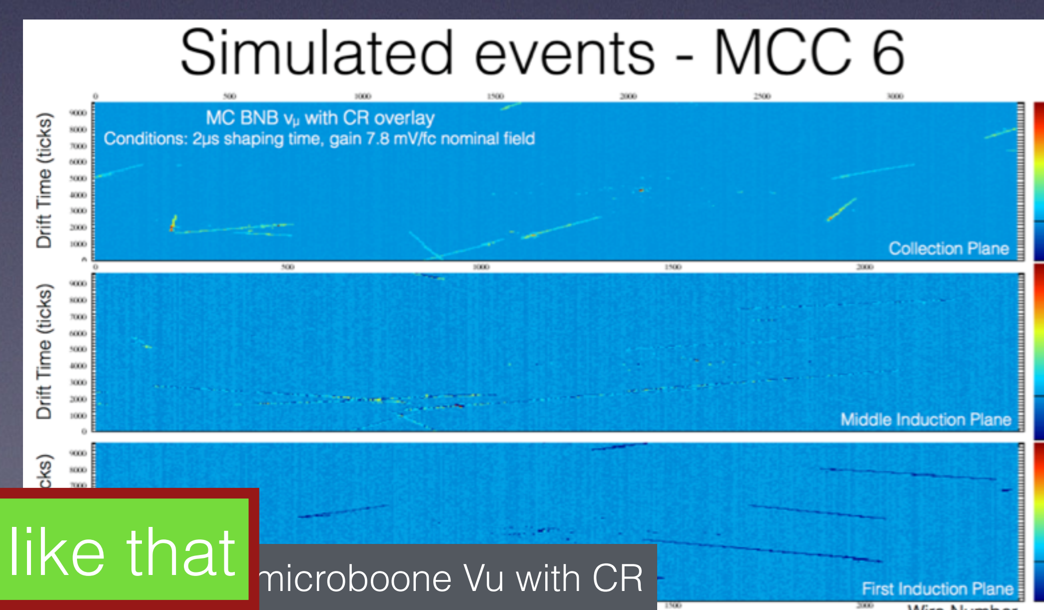






talk Dorota Stefan

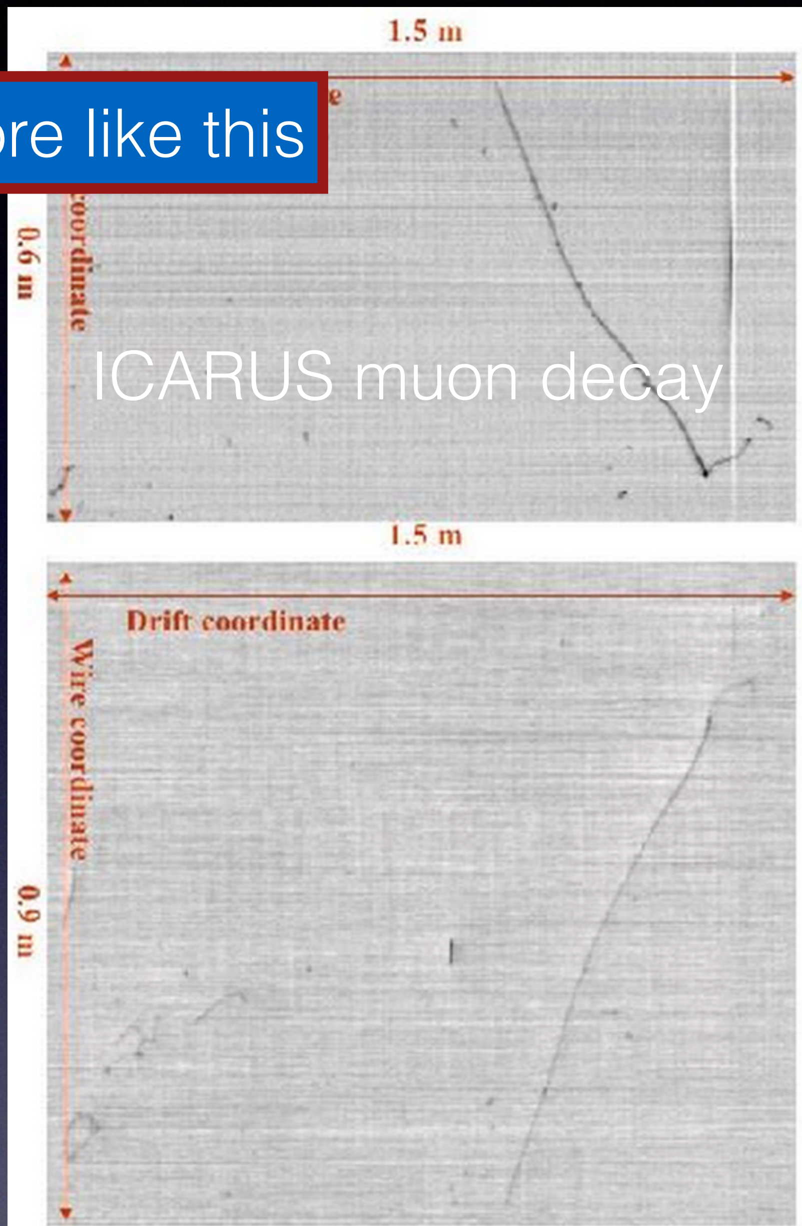


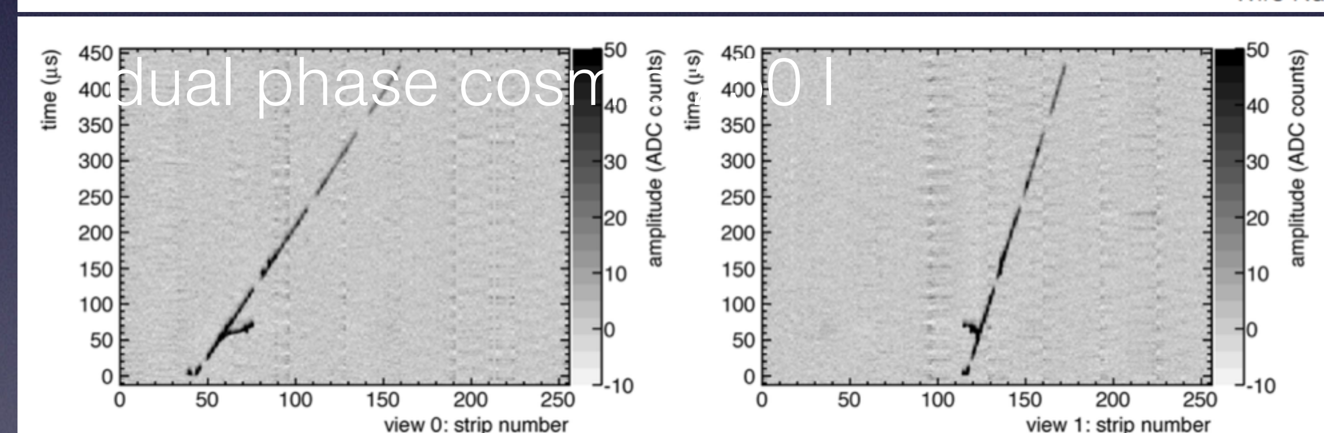


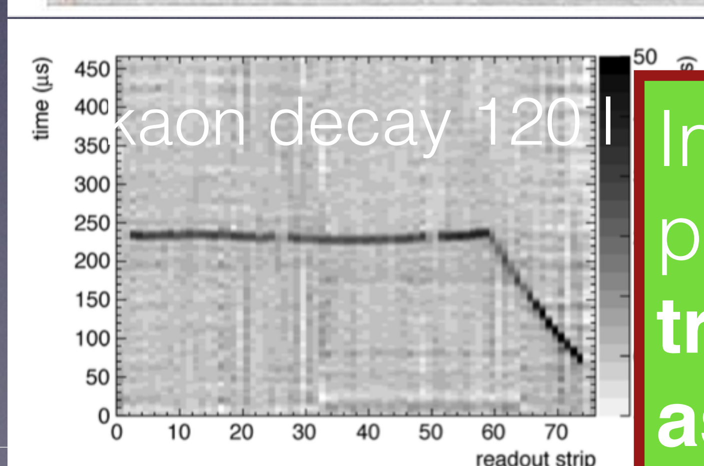
But remember that reality does does not really look like that

Event reconstruction

but more like this



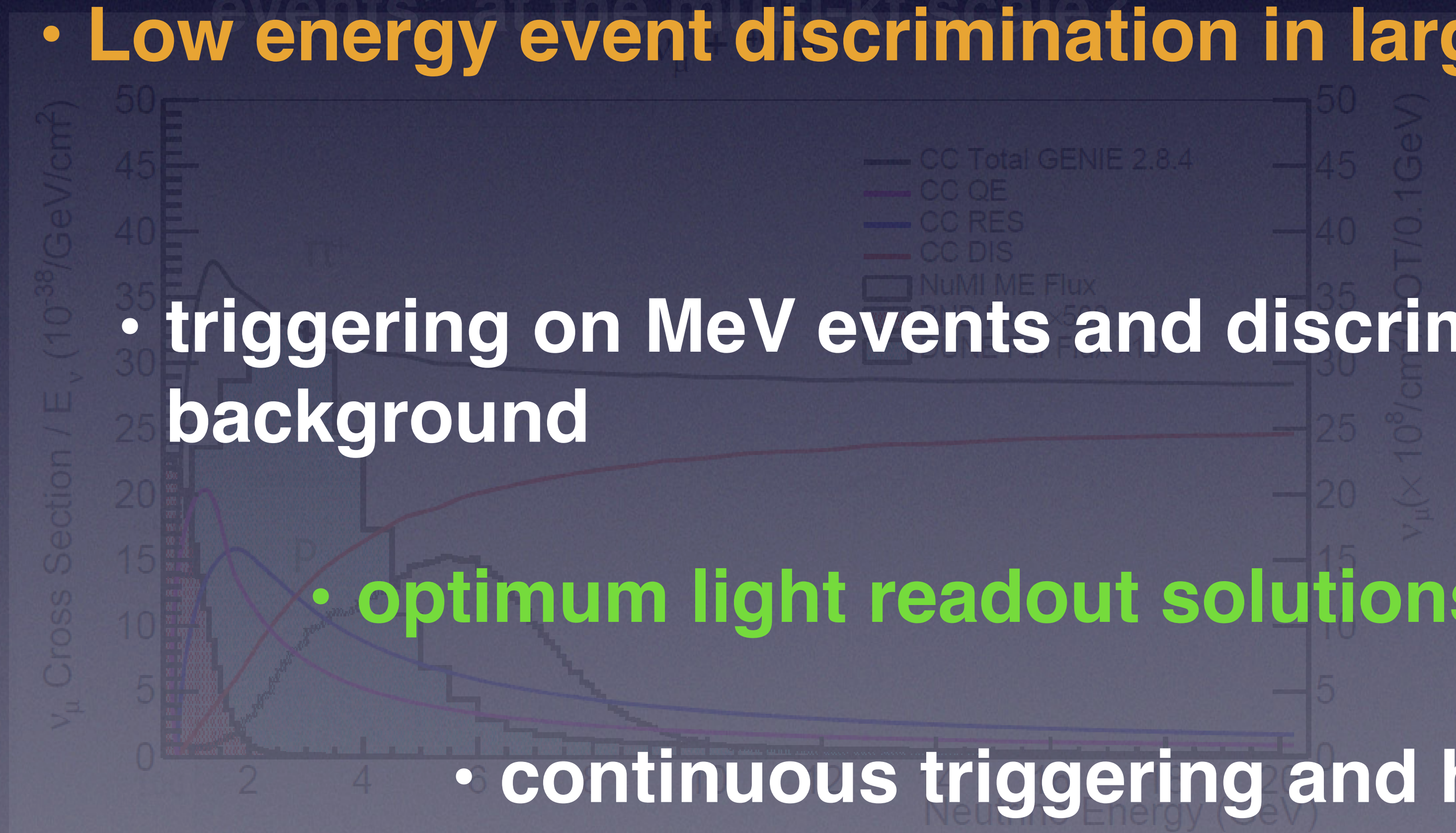




Important to spend time in constructing the best possible detector.
try to get the best possible S/N to get as close as possible to clean "MC like events"

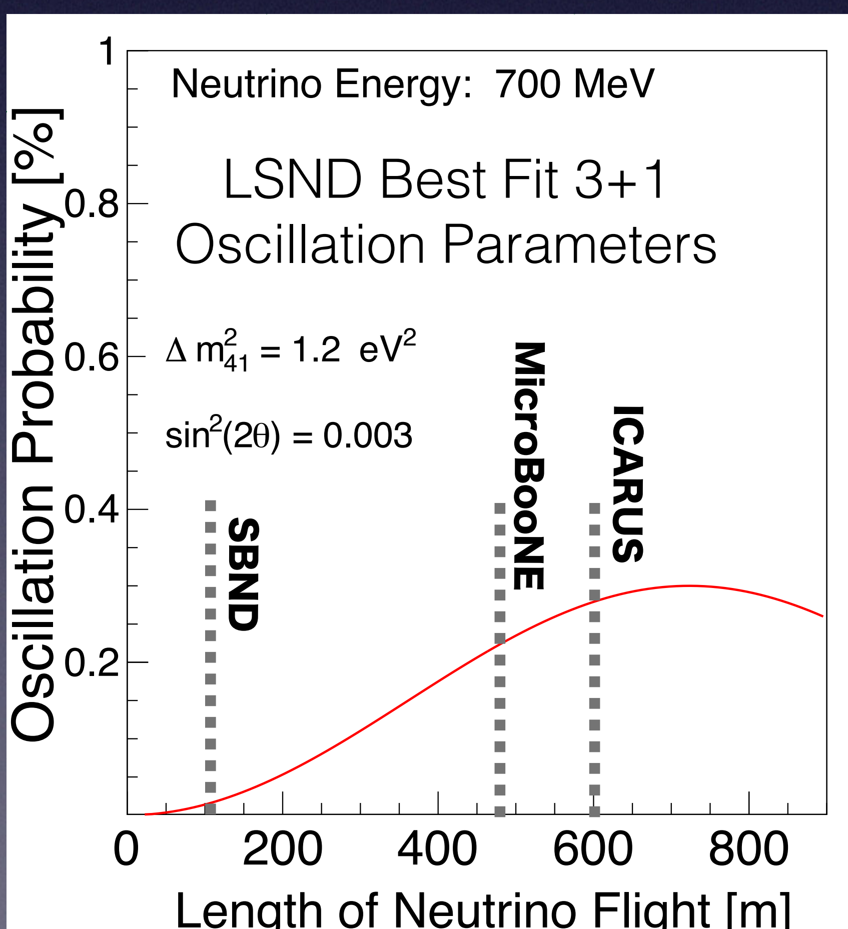
Near future: the main questions

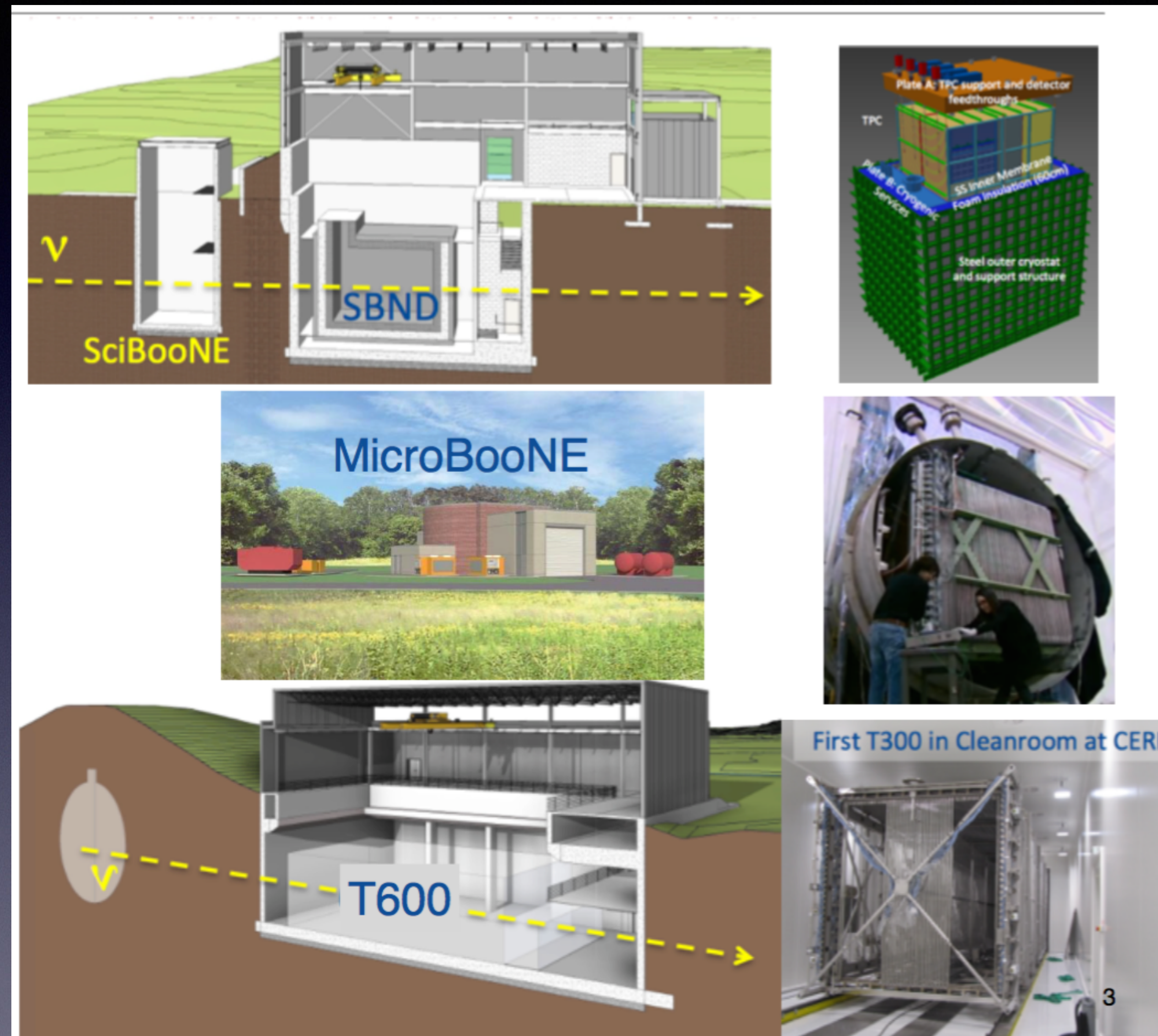
- **Can we safely generate very high voltage -180 kV single phase - 600 kV dual phase**
    - **What is the noise going to be like?**
- **Low energy event discrimination in large volumes and on the surface**
    - **triggering on MeV events and discriminating them form background**
        - **optimum light readout solutions**
            - **continuous triggering and huge data throughput**



Short baseline neutrino program

talk Roxanne Guenette

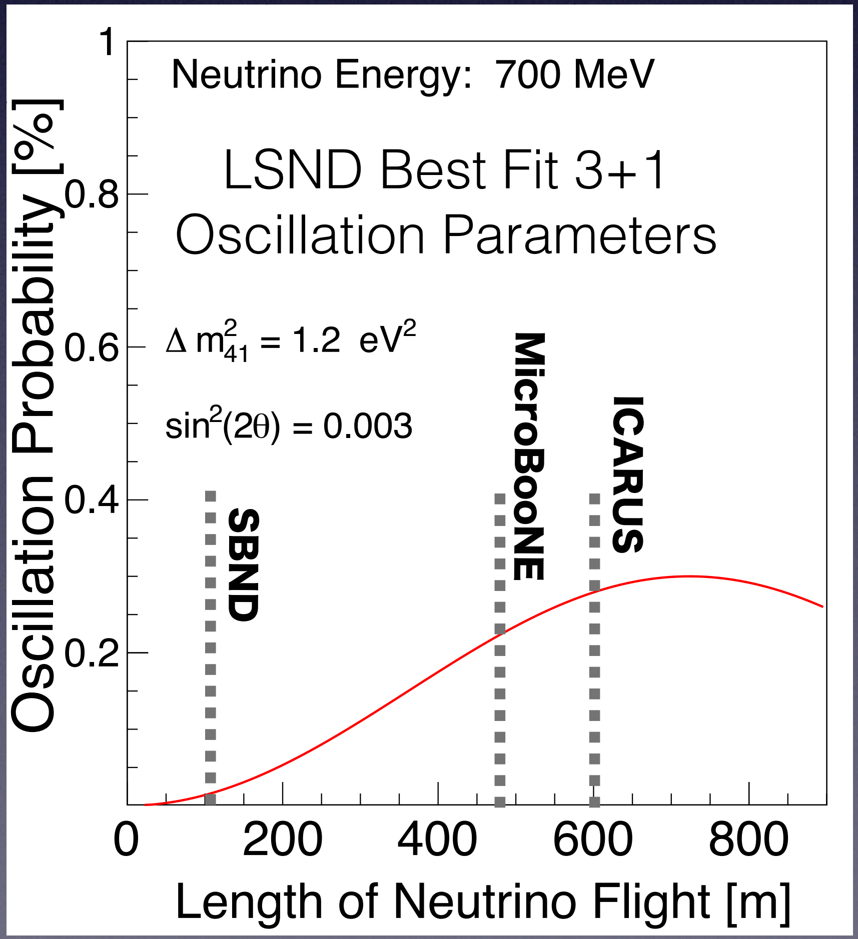


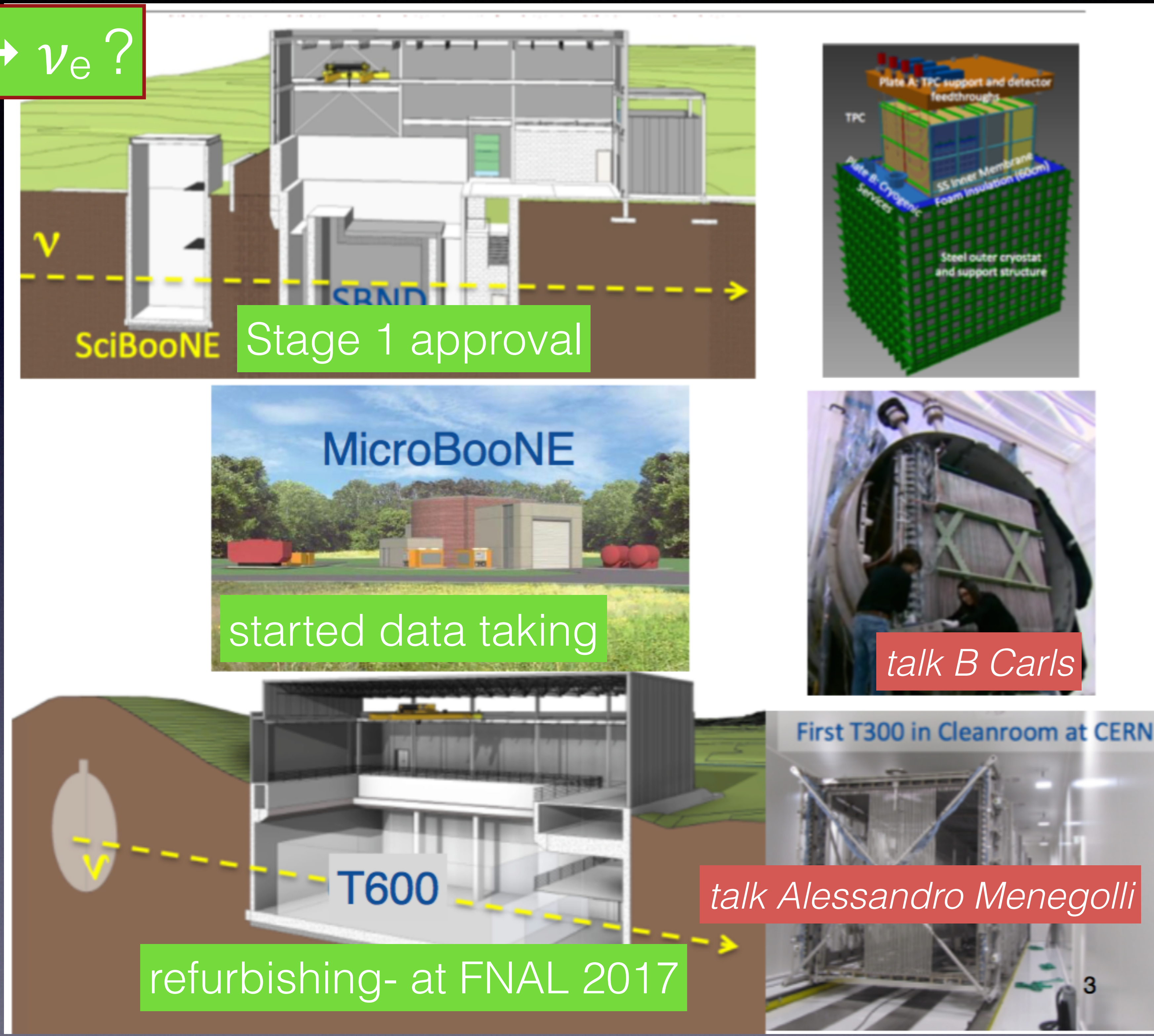


Short baseline neutrino program

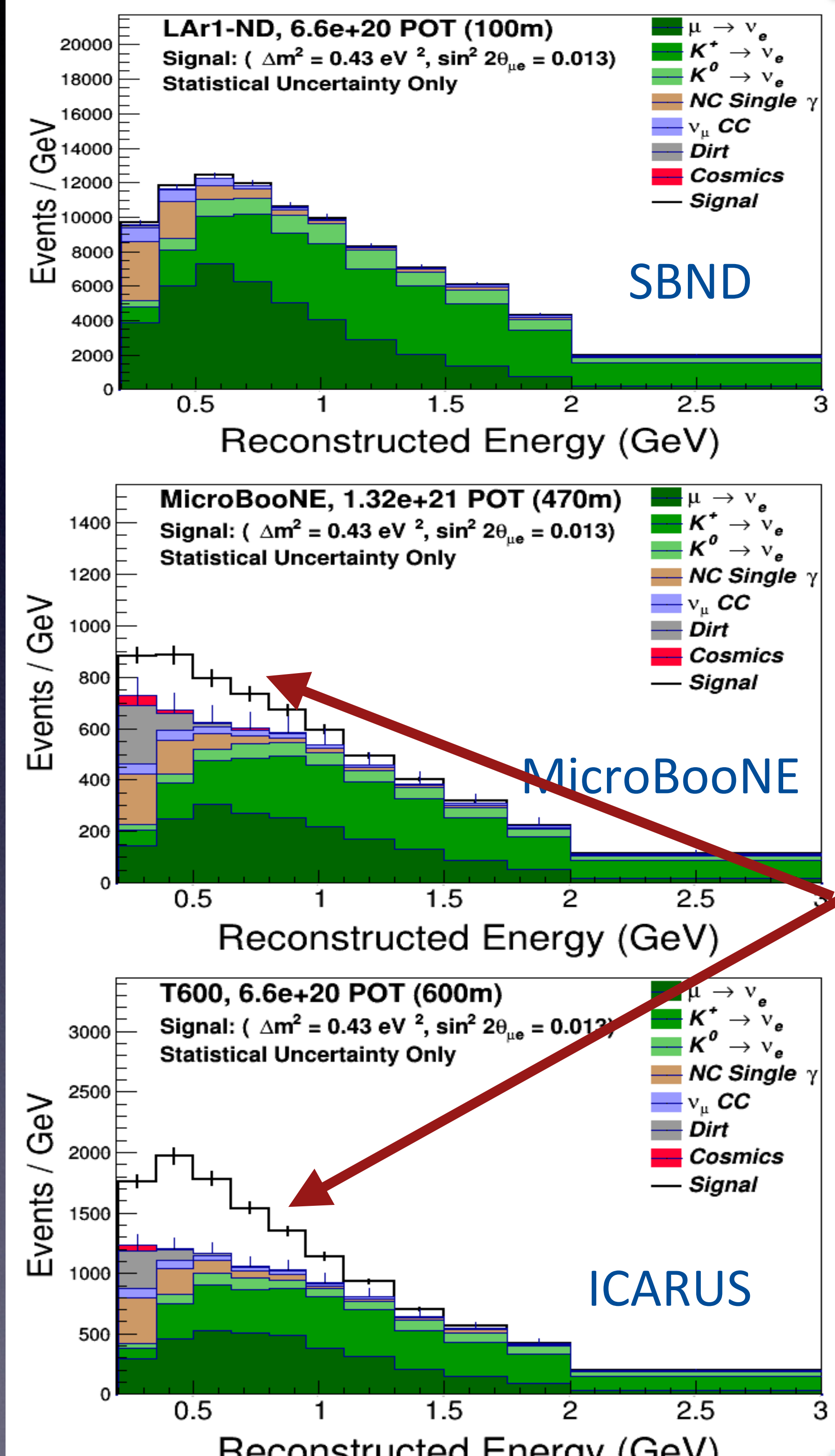
$\nu_\mu \rightarrow \nu_e$ or $\nu_\mu \rightarrow \nu_s \rightarrow \nu_e$?

talk Roxanne Guenette



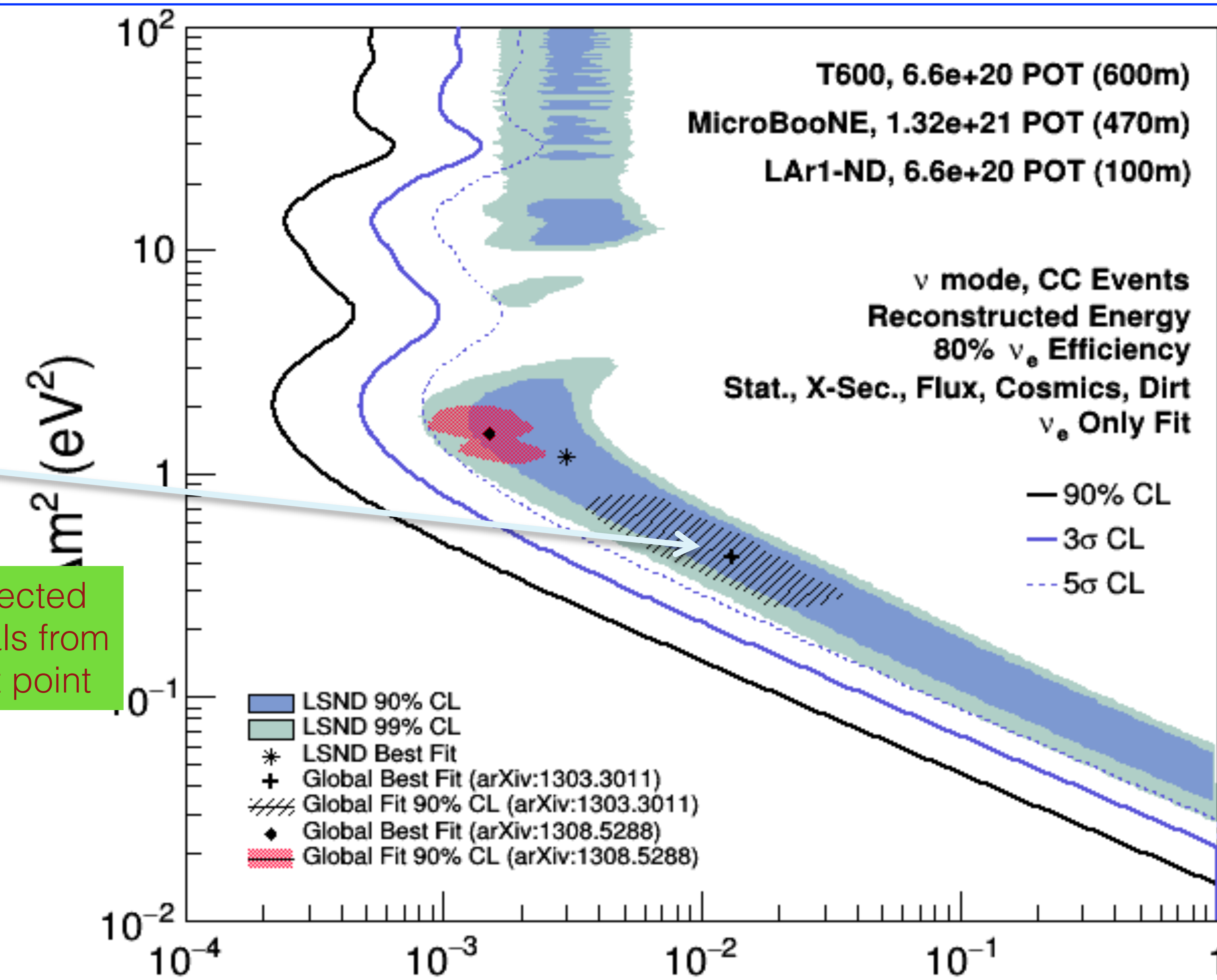


Short baseline neutrino program



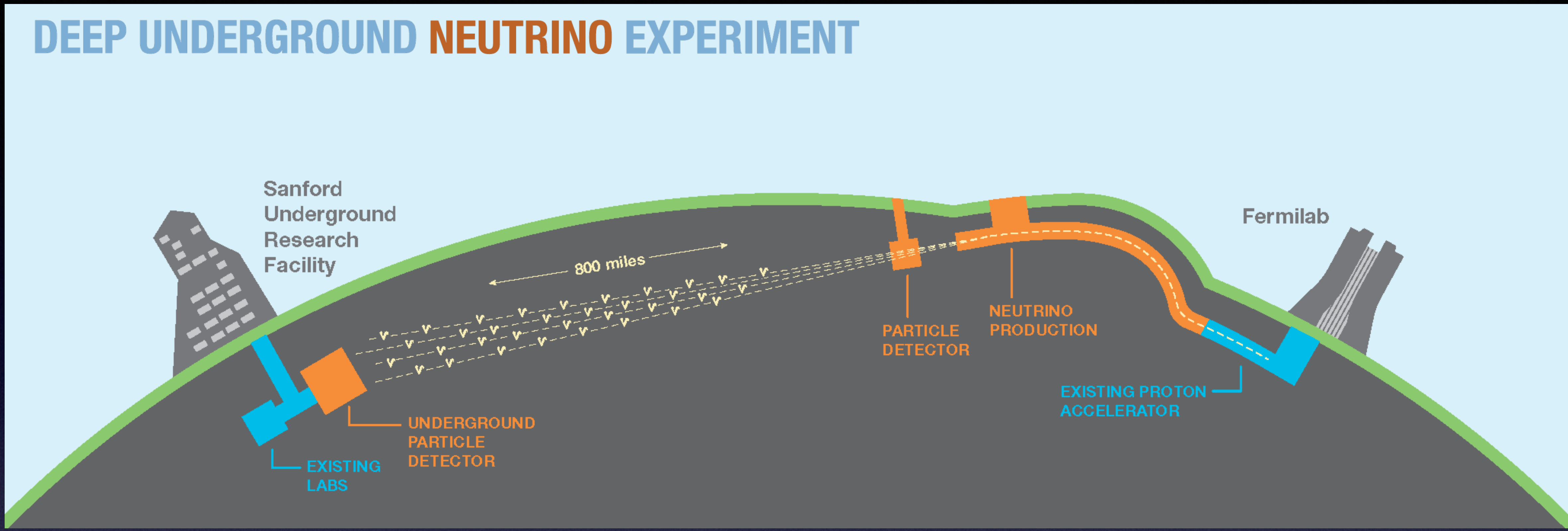
expected signals from at fit point

~5σ coverage of LSND 99% CL Region for 6.6x10^{20} P.O.T. ~ 3 years (13.2x10^{20} for MicroBooNE)



in ~5 years from now we will know

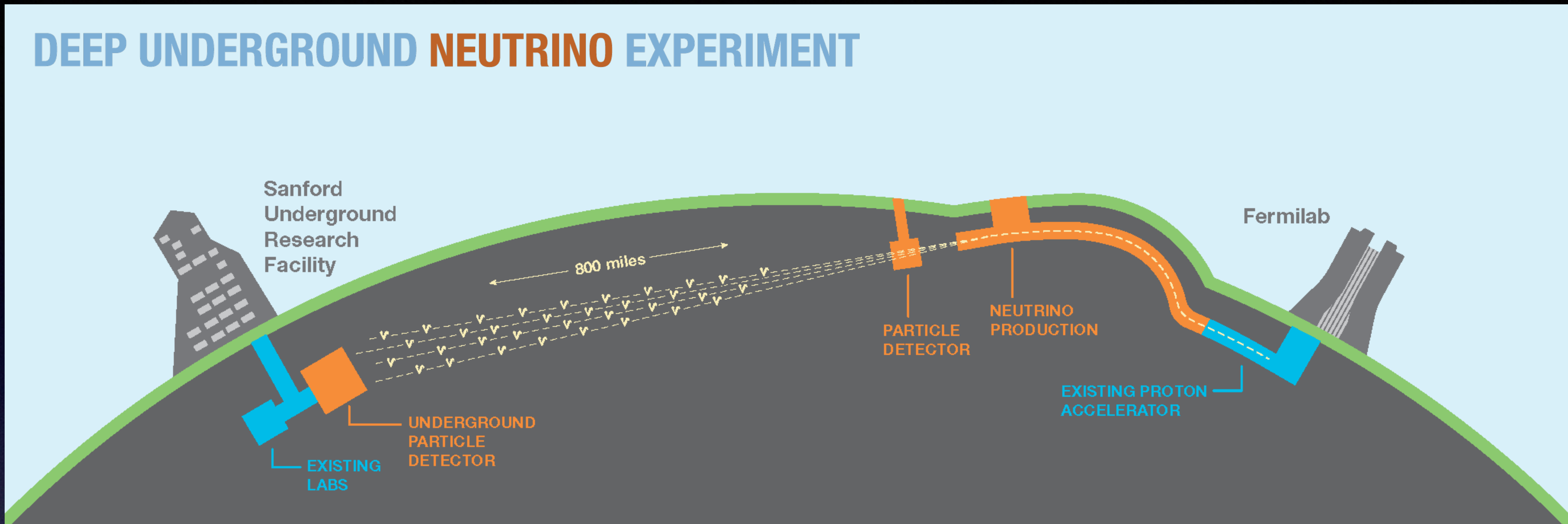
Long baseline neutrino program

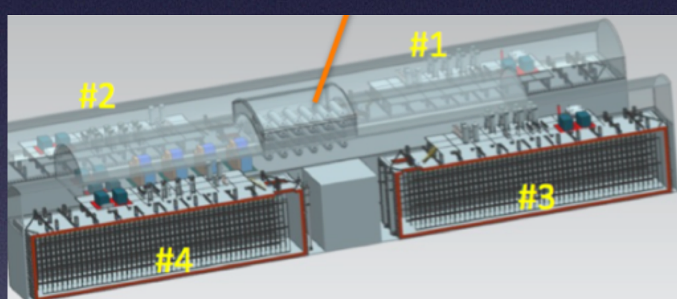


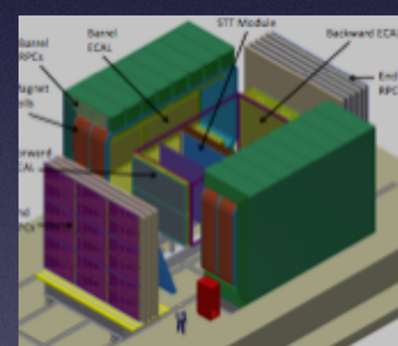
- ✓**Measurement of CP-violating phase** (δ_{CP}) P5 goal of 3 sigma coverage of 75% of δCP phase space by 850-1300 kt-MW-years.
- ✓**5 sigma sensitivity to mass hierarchy** for all values of δCP by 400 kt-MW-years
- ✓**proton decay** (~4×10^{35} p->Kν => increase current limits of an order of magnitude)
- ✓**supernovae neutrino detection** (o(10'000) neutrino SN explosion @10kpc)
- ✓**and also:** precision measurement of neutrino oscillation parameters, test of 3-neutrino paradigm, nu_tau appearance, atmospheric neutrinos, precise x-section measurements in near detector,… *talk Thomas Kutter*

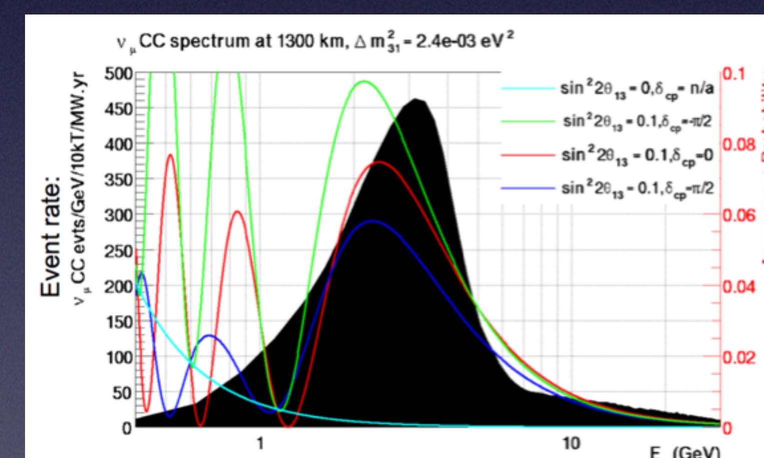
talk Elizabeth Worcester

Long baseline neutrino program









four identical cryostats deep underground . Staged approach to four independent 10k LAr detector modules. single phase and double phase readout under consideration

high precision near detector

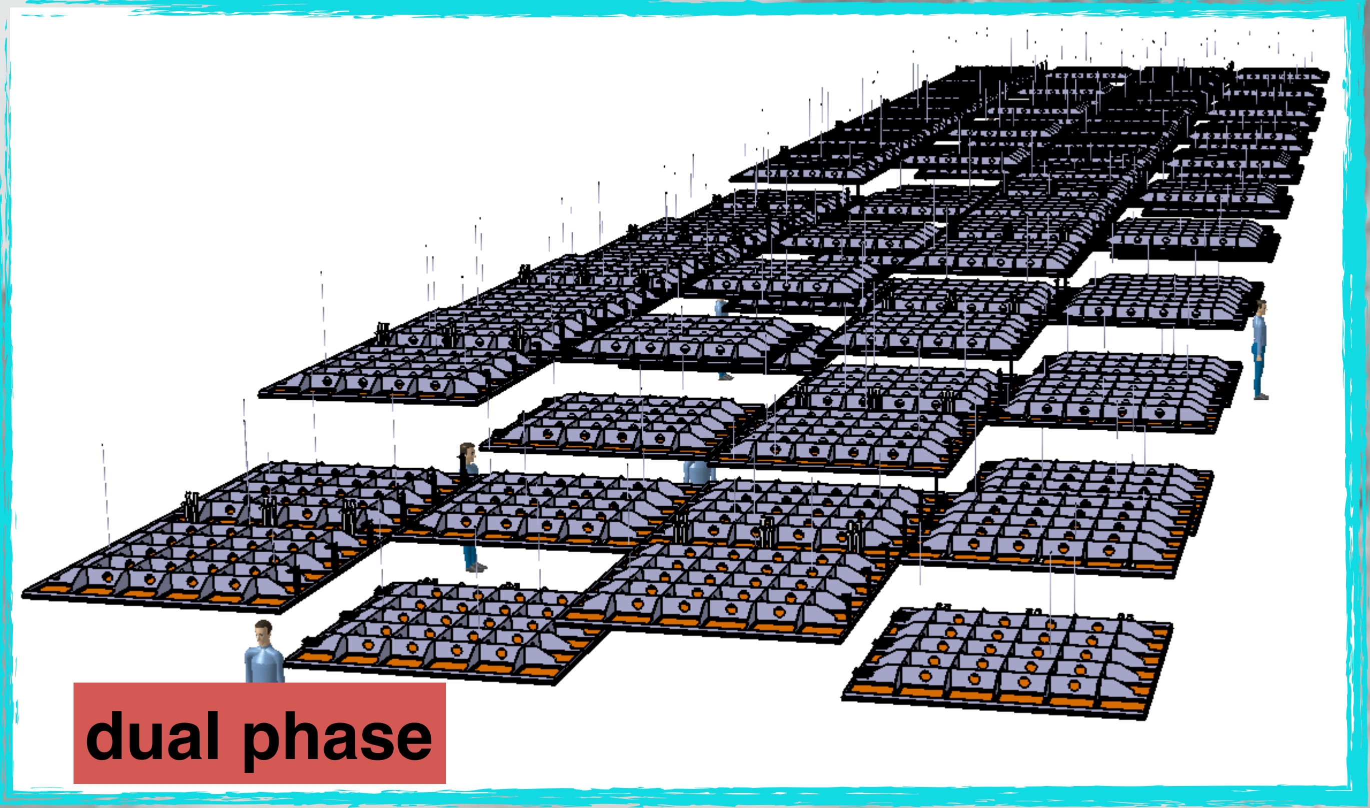
talk Thomas Kutter

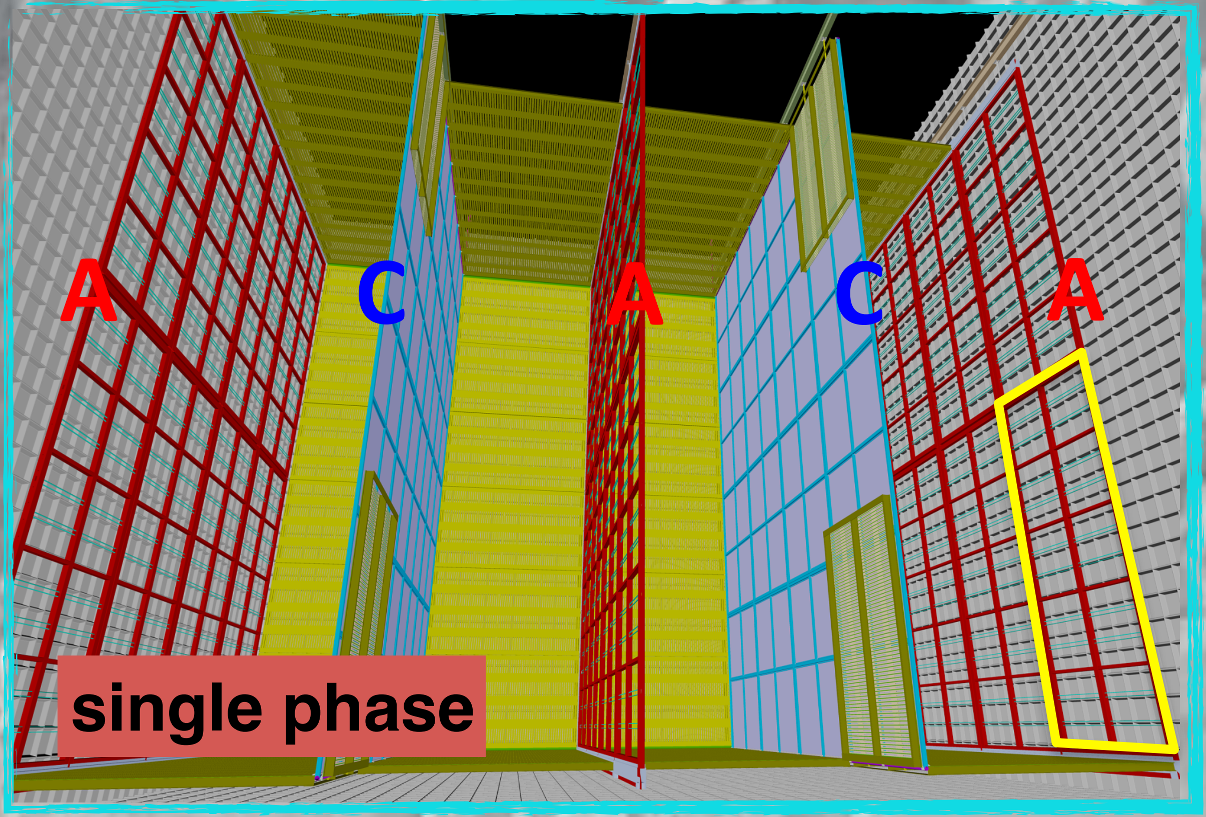
wide band high purity ν_μ beam with peak flux at 2.5 GeV operations at 1.2 MW and upgradeable.

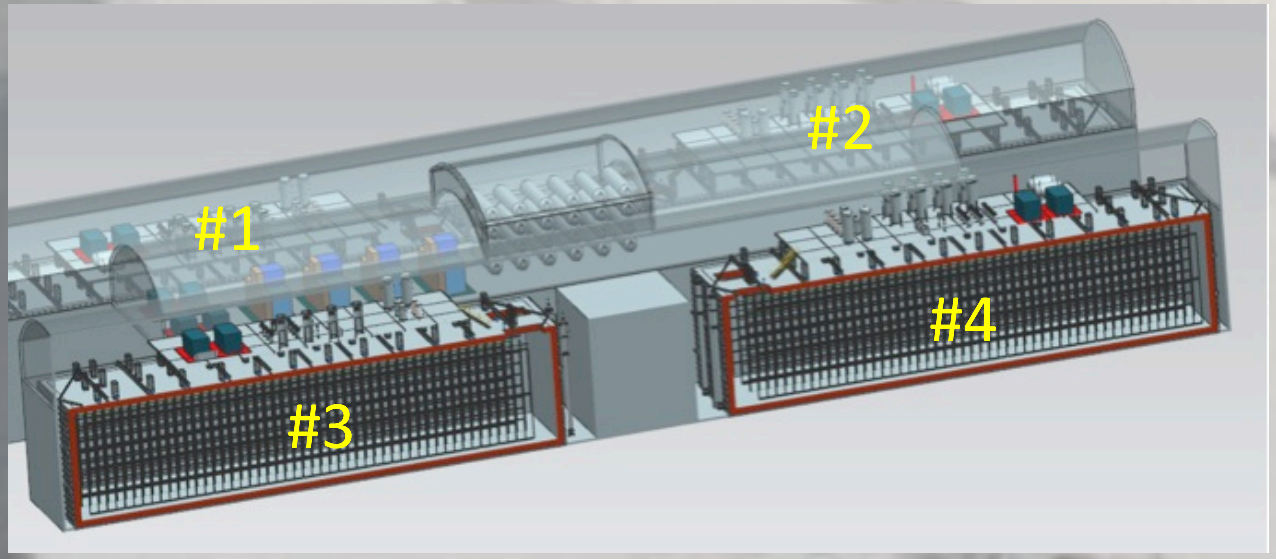
talk Elizabeth Worcester

DUNE far detector - Lead South Dakota

Modular detectors provides flexibility for evolution of LArTPC technology

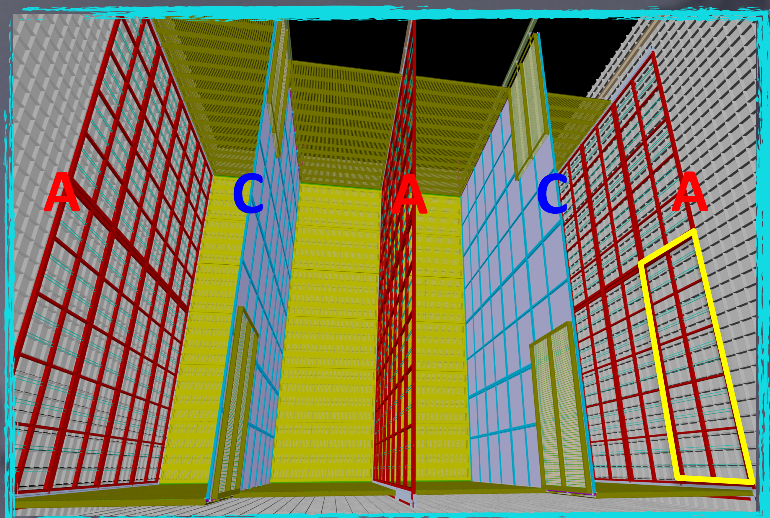






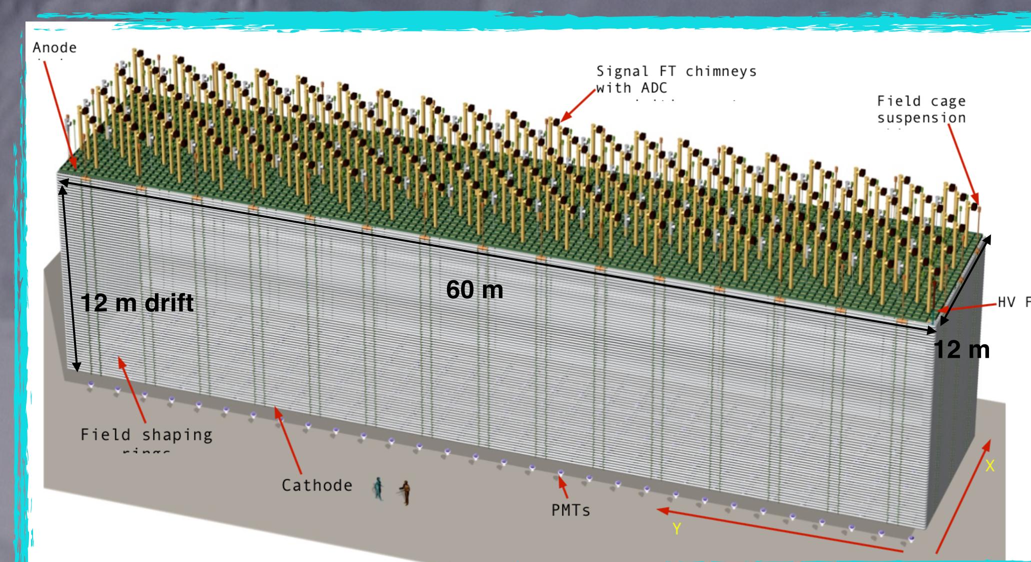
DUNE schedule and critical decisions

worth exploring two different technologies each having their own advantages and risks.



Performance relies crucially on the noise level. And difficult to predict what the level of noise will be on a 12x60x12 m TPC. Signal dependence on purity.

<u>Decouple from risks that may cripple your signal</u> such as unforeseen noise, lower than expected purity.
Guaranteed reach of low energy events.
But requires proof on the large scale of VHV and amplification



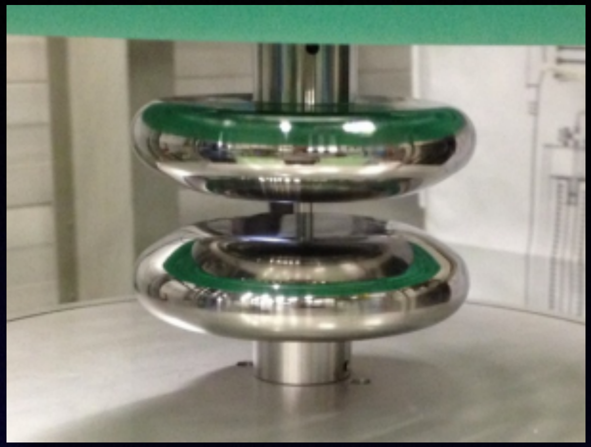
Before going underground both detector concepts will be tested at CERN ~2018-2019

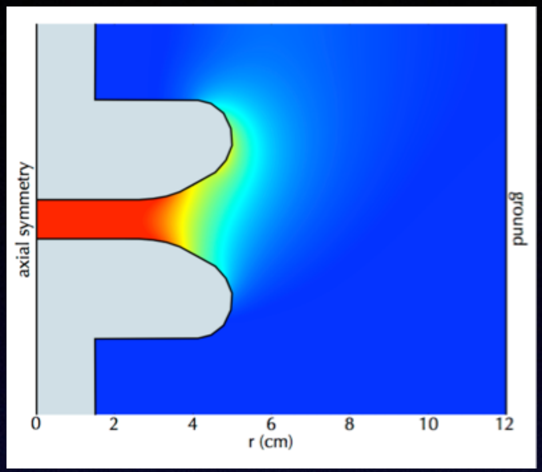
Going big: going to very high voltages

Detector	Active Lar	drift length	HV (500 V/cm) 1.5 mm/us	HV (500 V/cm) 2 mm/us
SBND	82t	2 m	-100 kV	- 200 KV
MicroBooNE	89t	2.5 m	- 125 kV	-250 kV
ICARUS T600	476t	1.5 m	- 75 kV	- 150 kV
DUNE single phase	10 kt	3.6 m	-180 kV	- 360 kV
DUNE dual phase	10 kt	12 m	- 600 kV	- 1.2 MV

Going big: going to very high voltages

- **ETH**: up to 100 kV over 1 cm in non bubbling LAr. (http://arxiv.org/pdf/1401.2777v1.pdf)





- **Bern**: measurement as a function of purity (http://arxiv.org/abs/1406.3929)

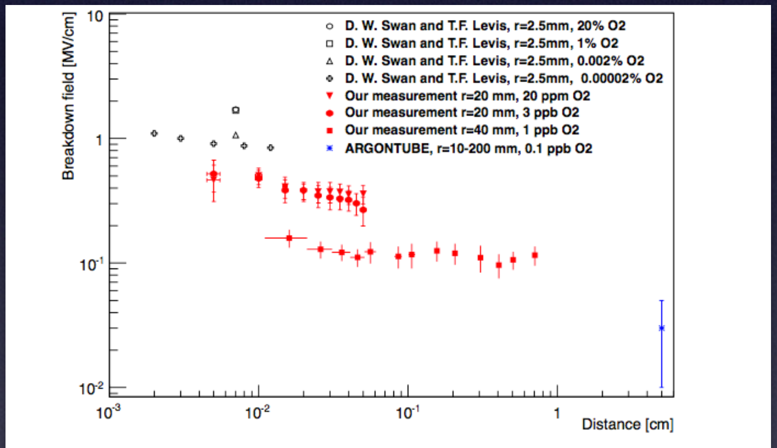
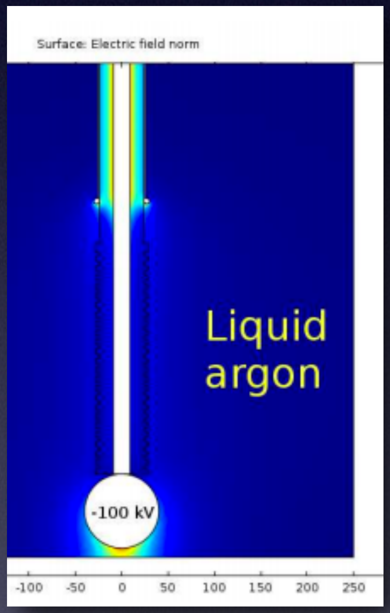
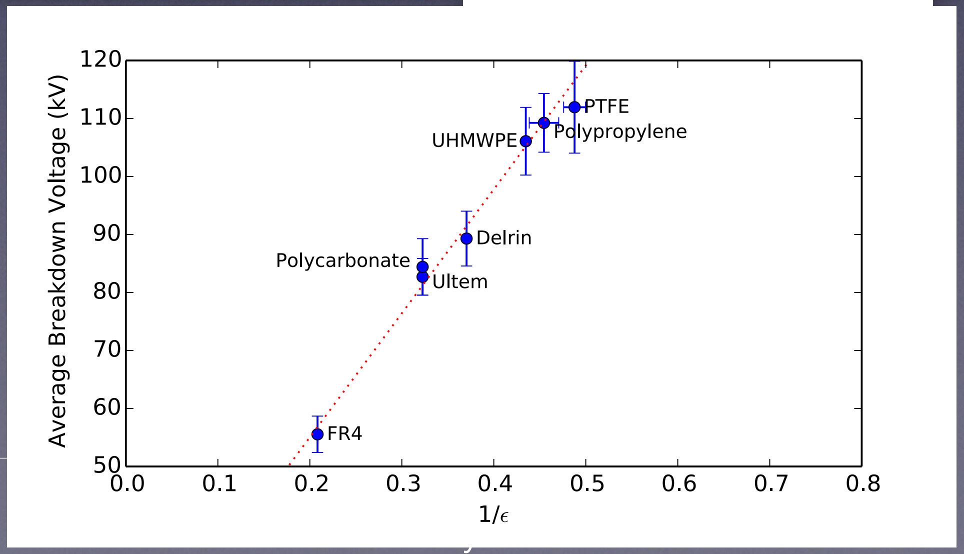


Figure 7. Compilation of the experimental data on the electric strength of liquid argon including results from our measurements.



- **Fermilab**: comparative test of insulators in a feedthrough-like geometry (http://arxiv.org/abs/1506.04185)

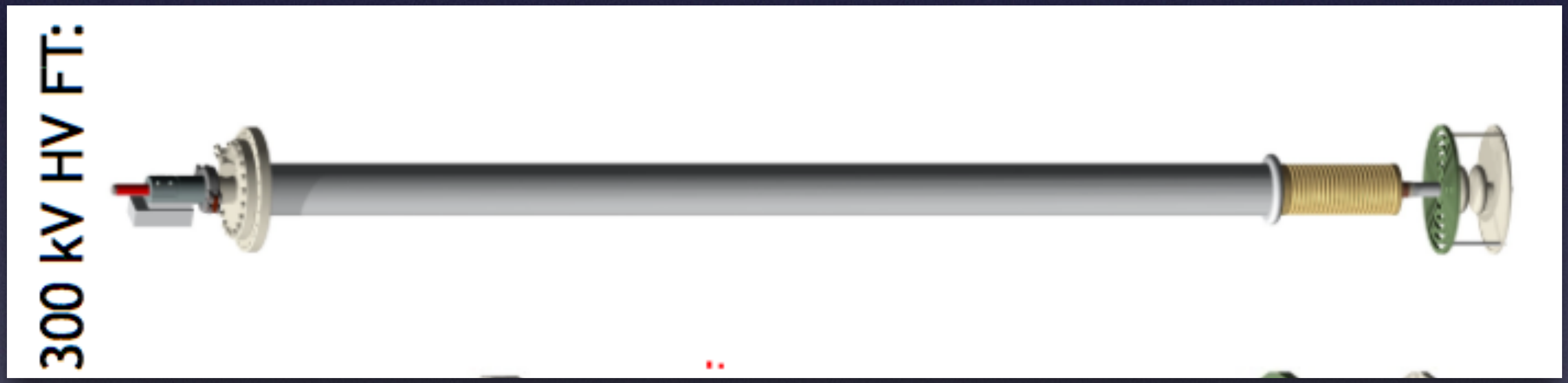


talk Sarah Lockwitz

Going big: going to very high voltages

up to 180 kV on the 35T feedthrough recently, (35T HV needs~113 kV)

WA105 300 kV feedthrough. In production, soon to be tested

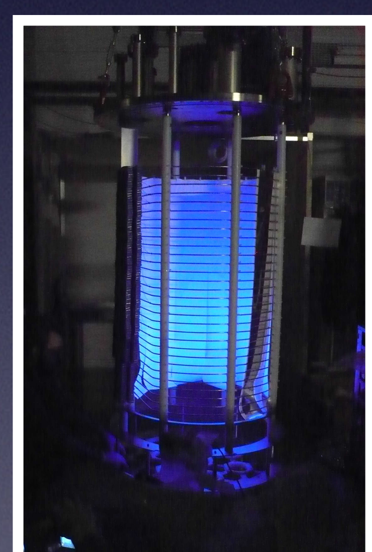


Remember that what matters is the electric field and not the absolute high voltage. Optimise the local geometry of the Feedthroughs, field cage, nearby ground to avoid high field regions.

Light readout solutions for Large detectors

- Argon scintillates with a high light yield (~40'000 photons/MeV @ 128 nm (MIP)).
- The primary purpose of the scintillation light is to provide the t0 hence drift coordinate of your even.
- continuous trigger operation of the detectors (nucleon decay, Supernovae,…).
- But also provides additional information (timing of SN events, charge sign discri,..)
- You want to maximise the light yield in photo detector device so that you trigger at the lowest possible energy threshold.

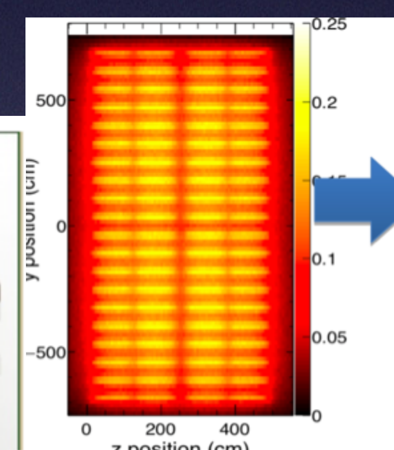
coated PMTs

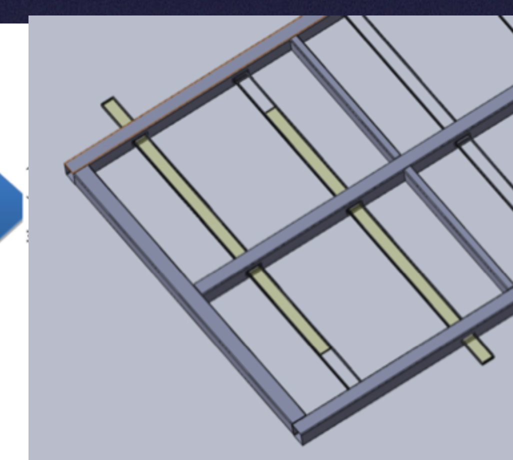


- proven technology in LAr (e.g DM experiments)
- excellent timing (ns)
- But bulky and requires HV

talk Andrzej Szelc

SiPM.



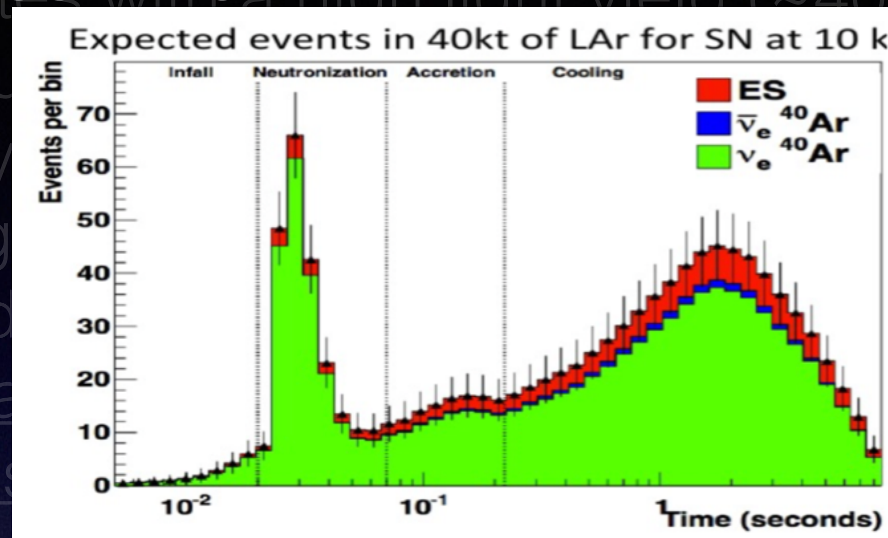


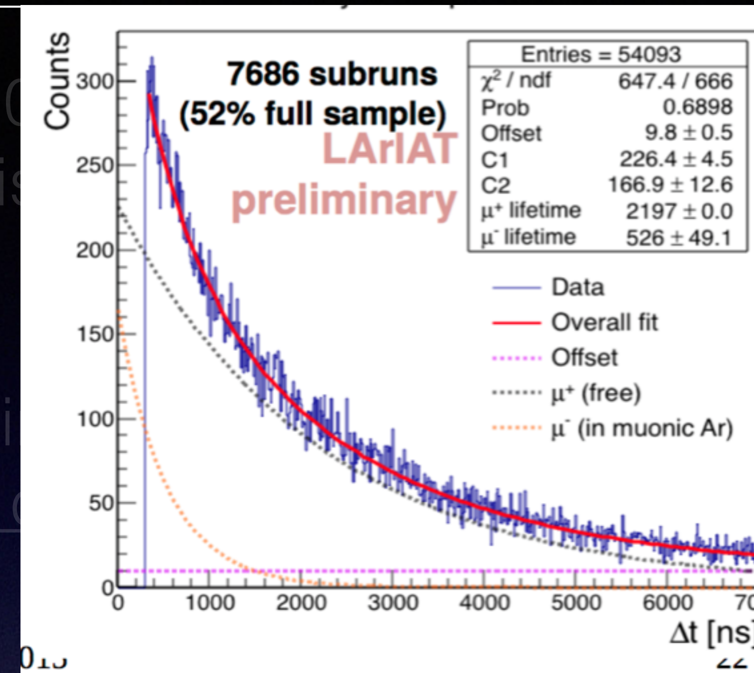
- small, low voltage.
- coated bars with SiPM (DUNE single phase design).
- Pb of attenuation in bars but work ongoing to minimise it.

also DM see Andrea Polar

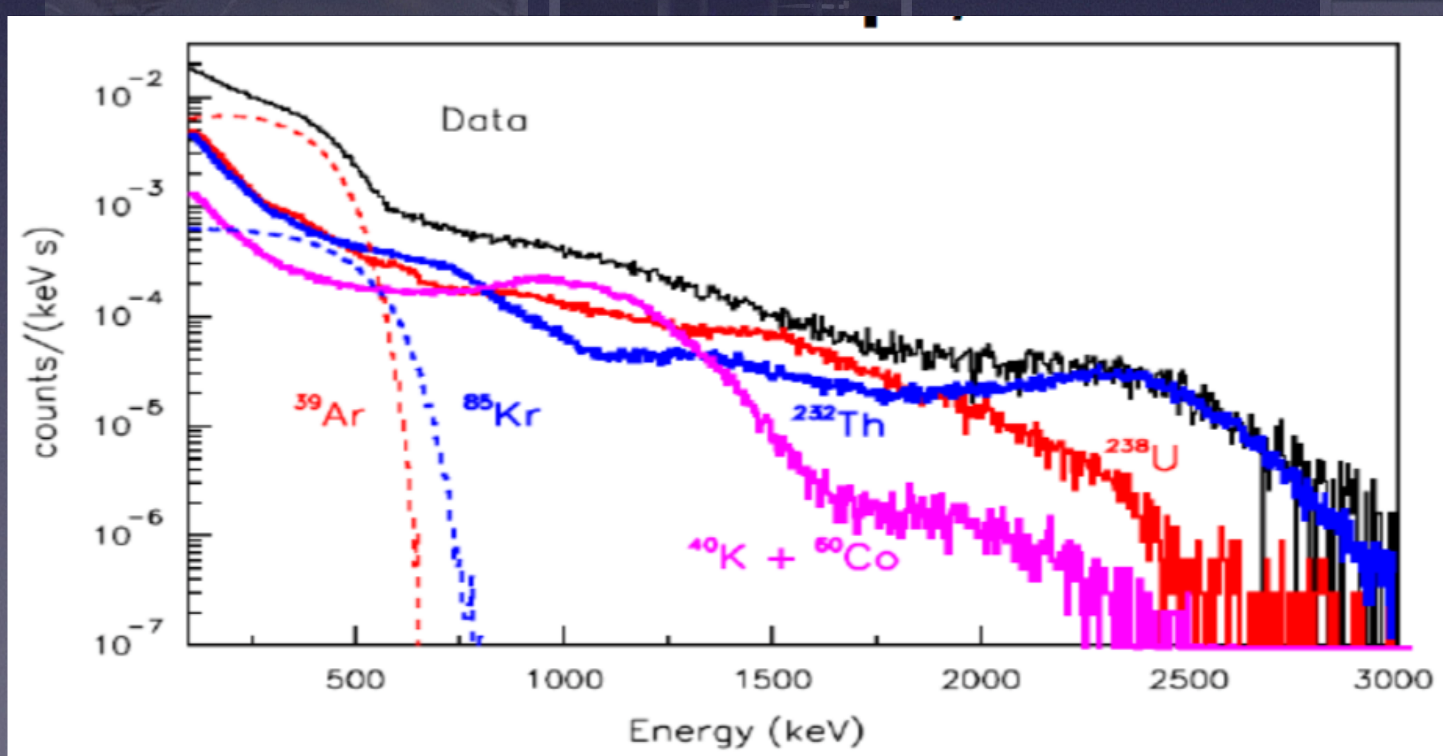
Light readout solutions for Large detectors

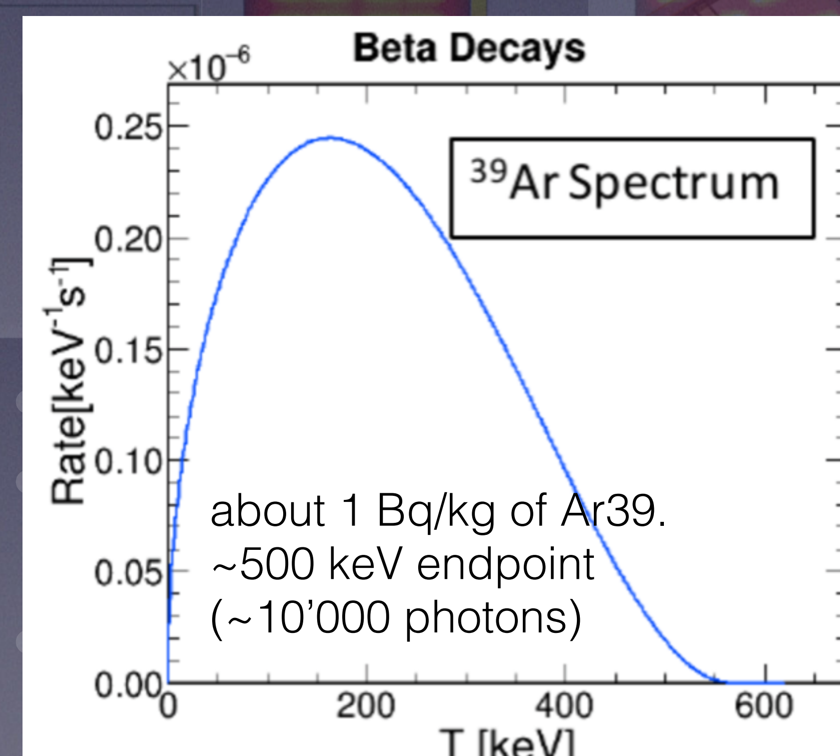
Not only for triggering





but off course the more sensitive you are …





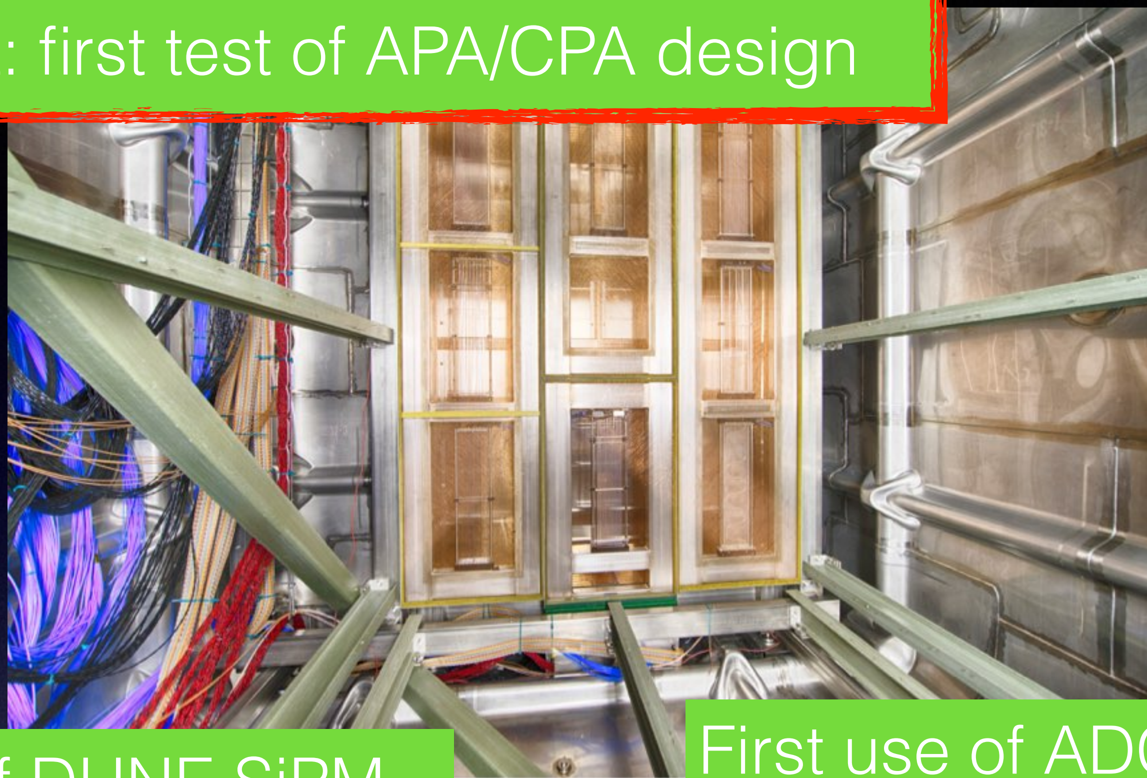
about 1 Bq/kg of Ar39.
~500 keV endpoint
(~10’000 photons)

DUNE single phase detector prototyping @ FNAL

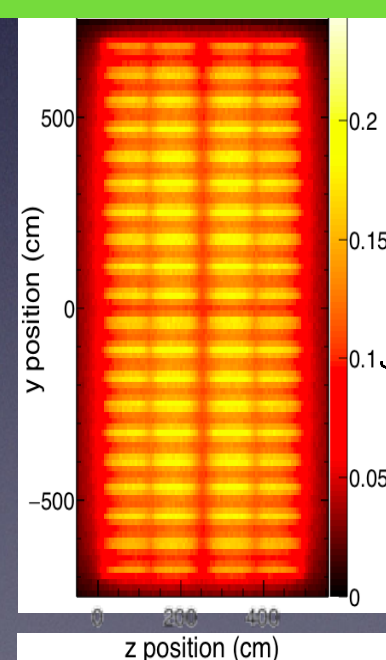
- DUNE FD will be largest single phase LAr-TPC ever constructed and presents multiple engineering and data processing challenges
  - Need to scale up cryostat, electronics
  - Cold digital electronics to minimize number of cables and cable length

- 35t and protoDUNE are prototype single phase LAr-TPC integrated detectors which will test FD design and components

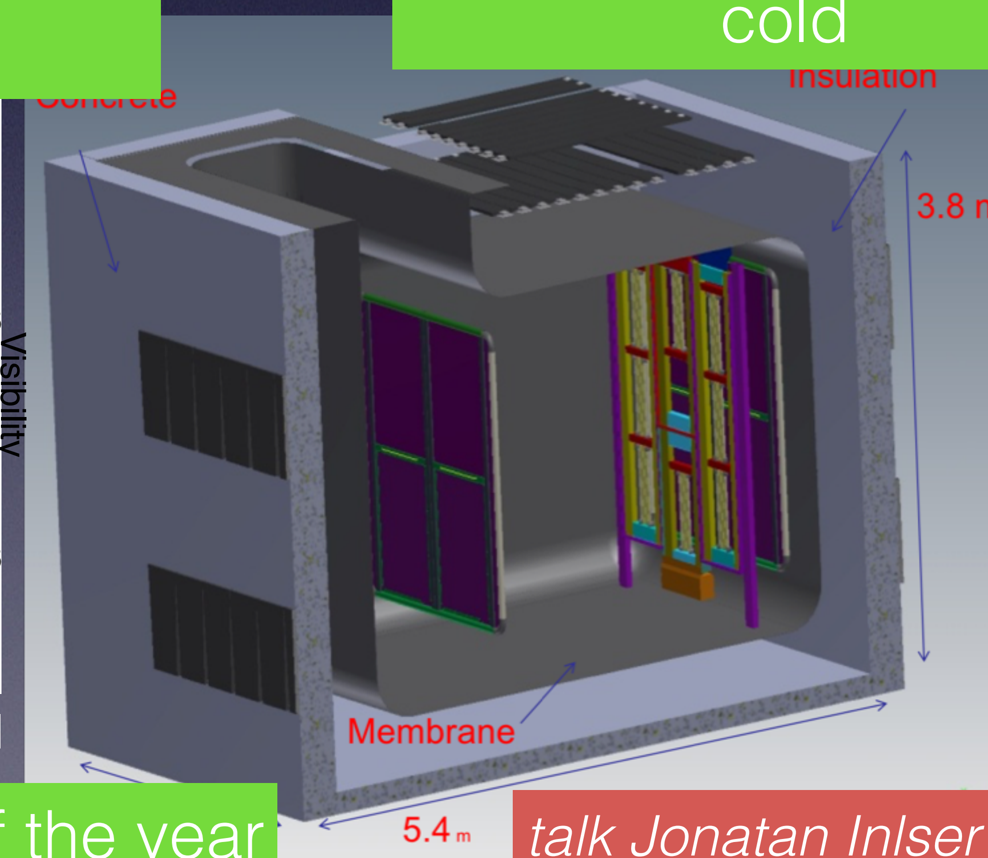
35 t: first test of APA/CPA design



Test of DUNE SiPM readout



First use of ADC ASI[C] cold



filling end of the year

talk Jonatan Inlser

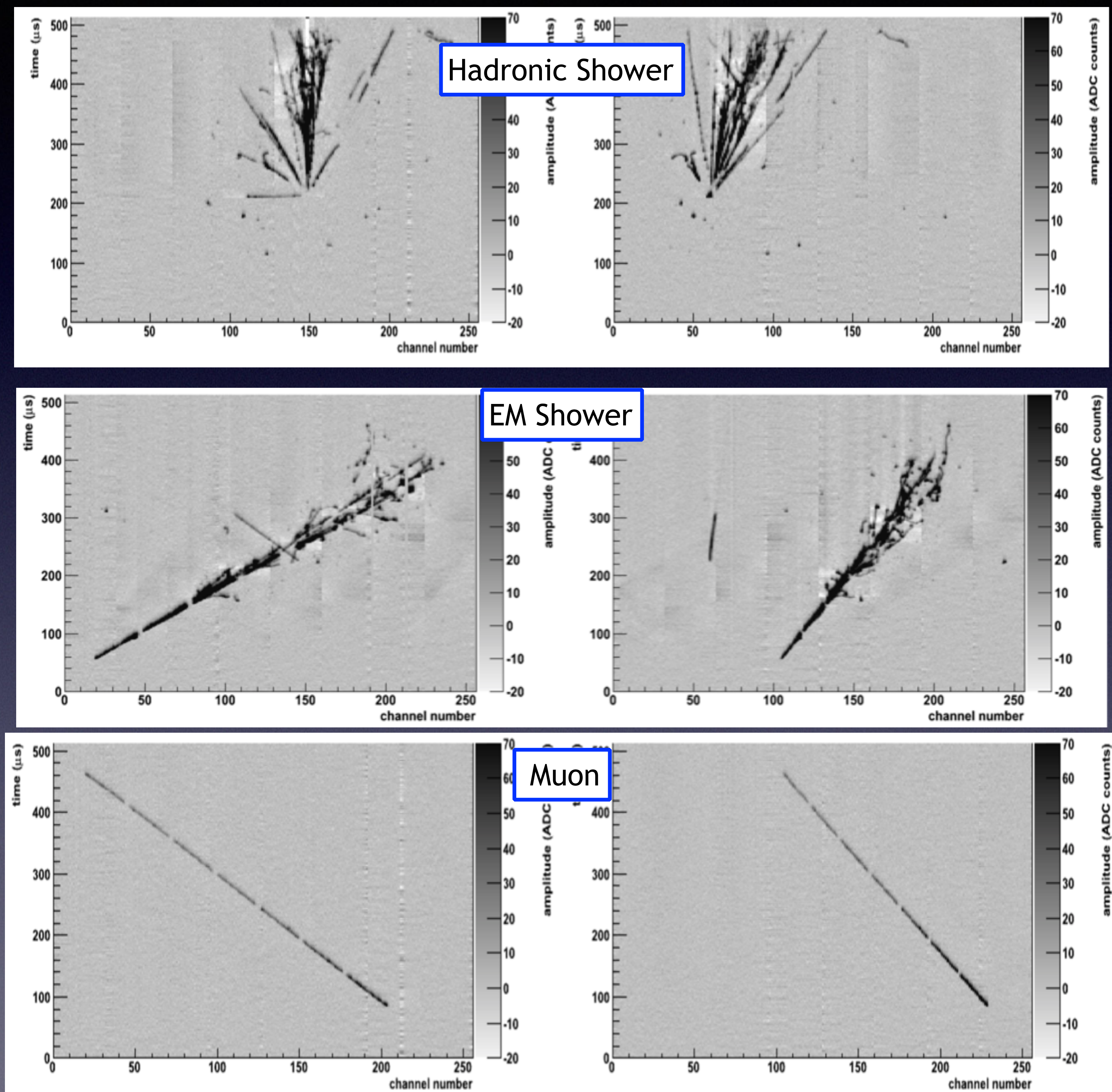
R&D towards large dual phase detectors

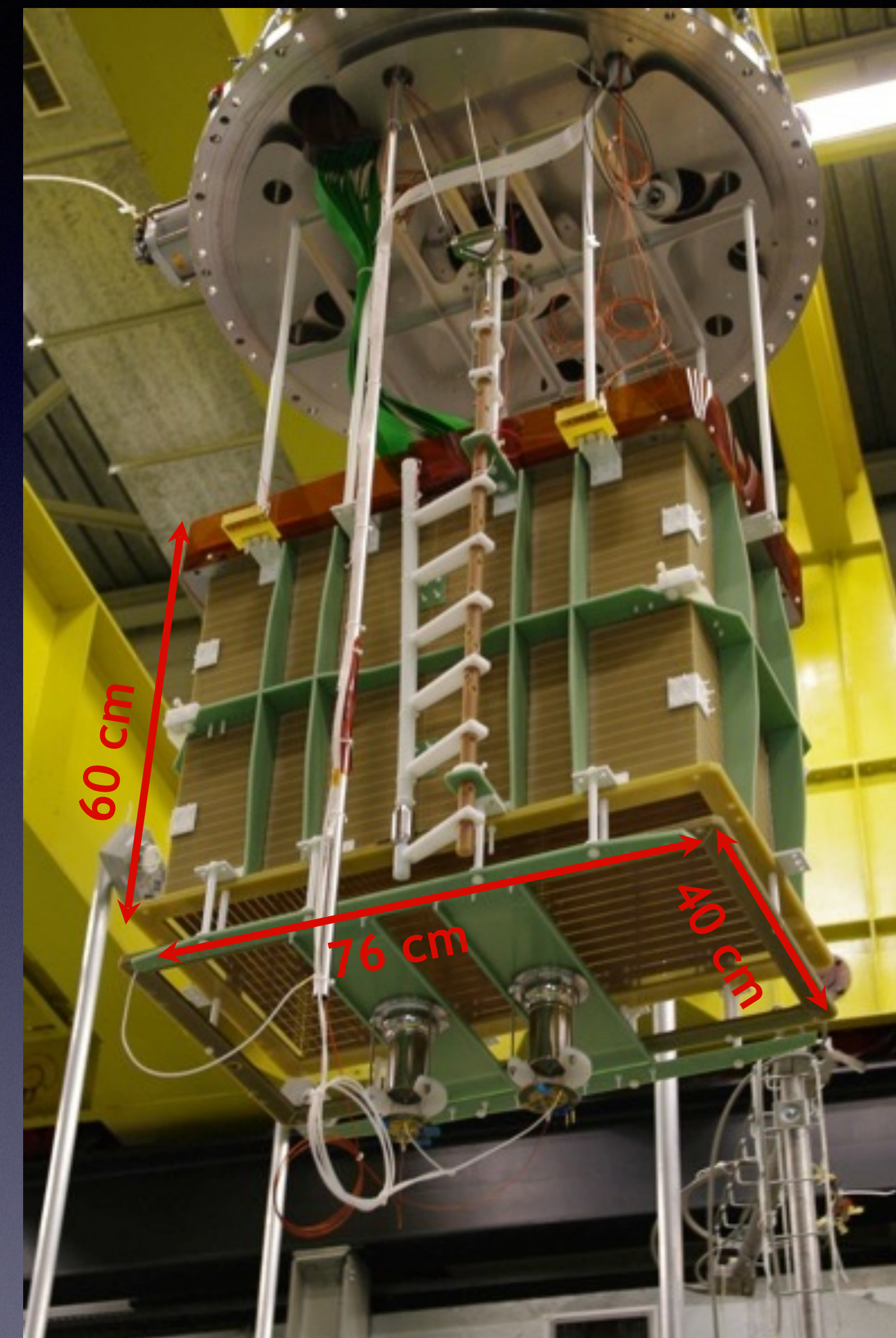
- ✳ Safe generation and transport of very high voltage (up to 1 MW) for long distance drift.
- ✳ Stable and uniform amplification and readout in pure Ar vapour on large areas.
- ✳ Uniformity of charge collection.
- ✳ purchase of large number of LEMs and anodes (design, purchase, cleaning and QA)
- ✳ Accessible cold front-end electronics
- ✳ Large hanging field cage structure
- ✳ chimneys, feedthroughs and slow control sensors

WA105

22 institutes 122 physicists

Technology proven on small detectors

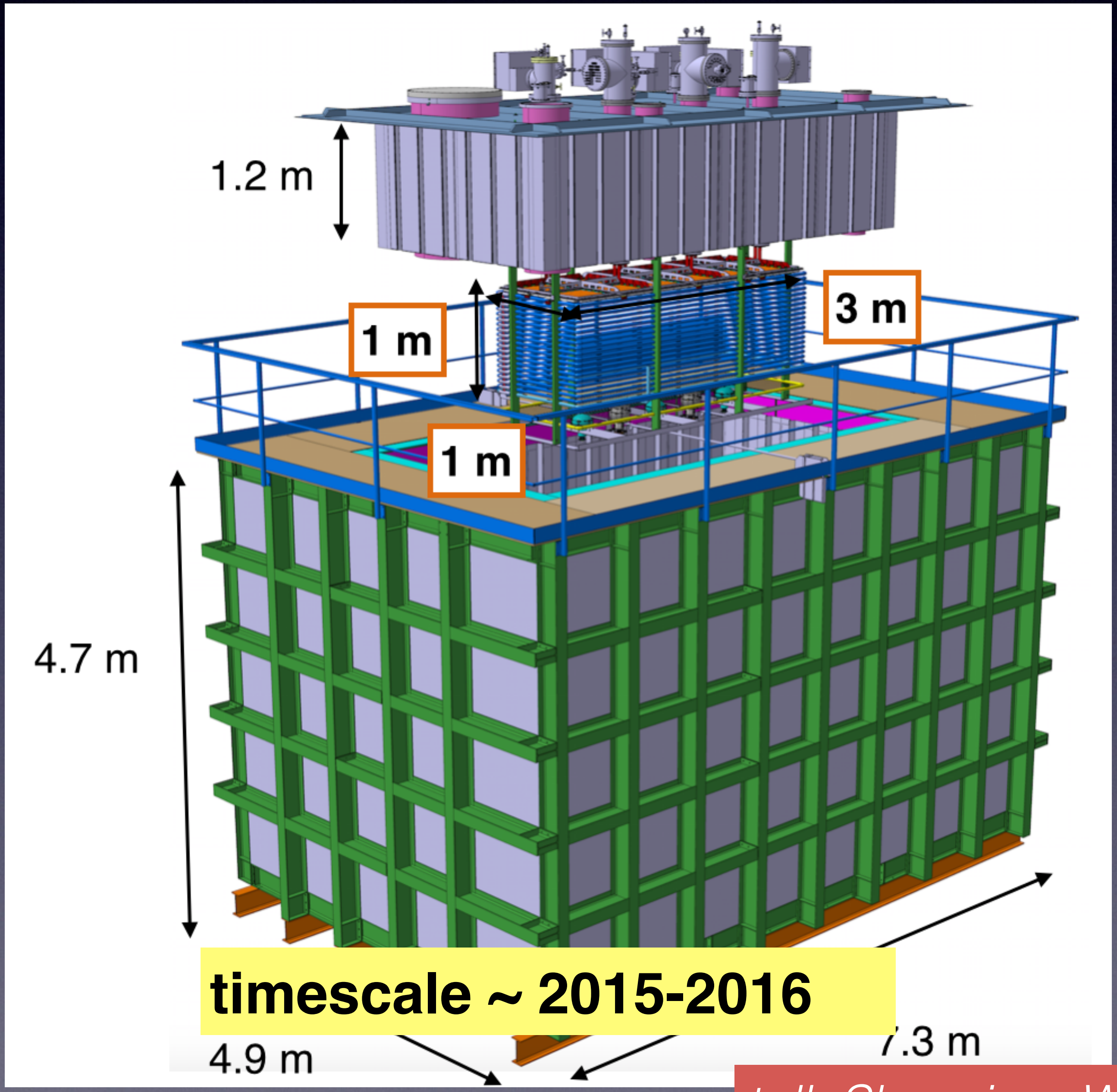




Prototyping at CERN: dual phase

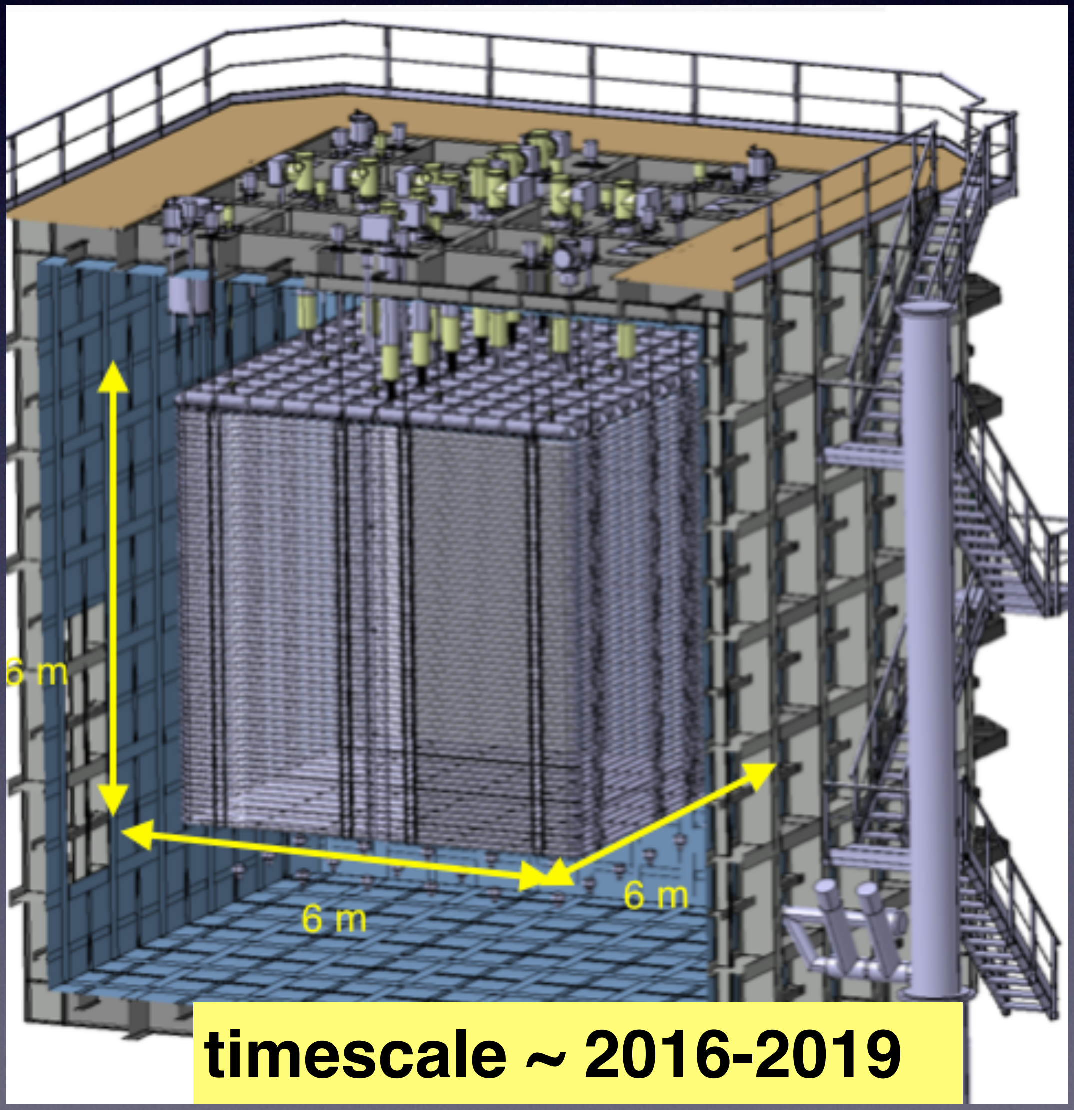
two Demonstrators closely linked with different timescales

LAr-Proto
(3x1x1 m^3 active 24 ton LAr total)



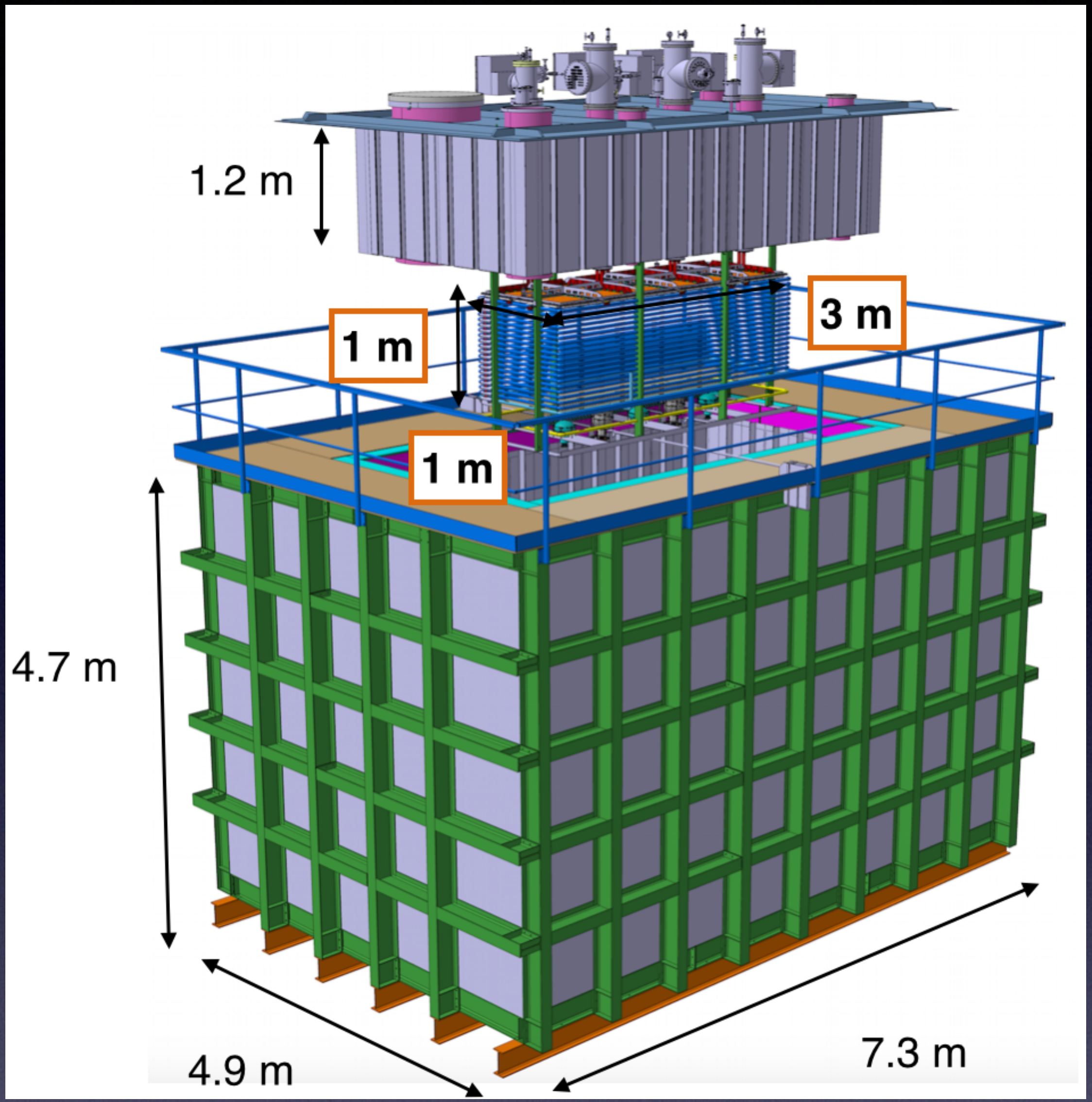
talk Shuoxing Wu

DLAr
(6x6x6 m^3 active 700 ton LAr total)



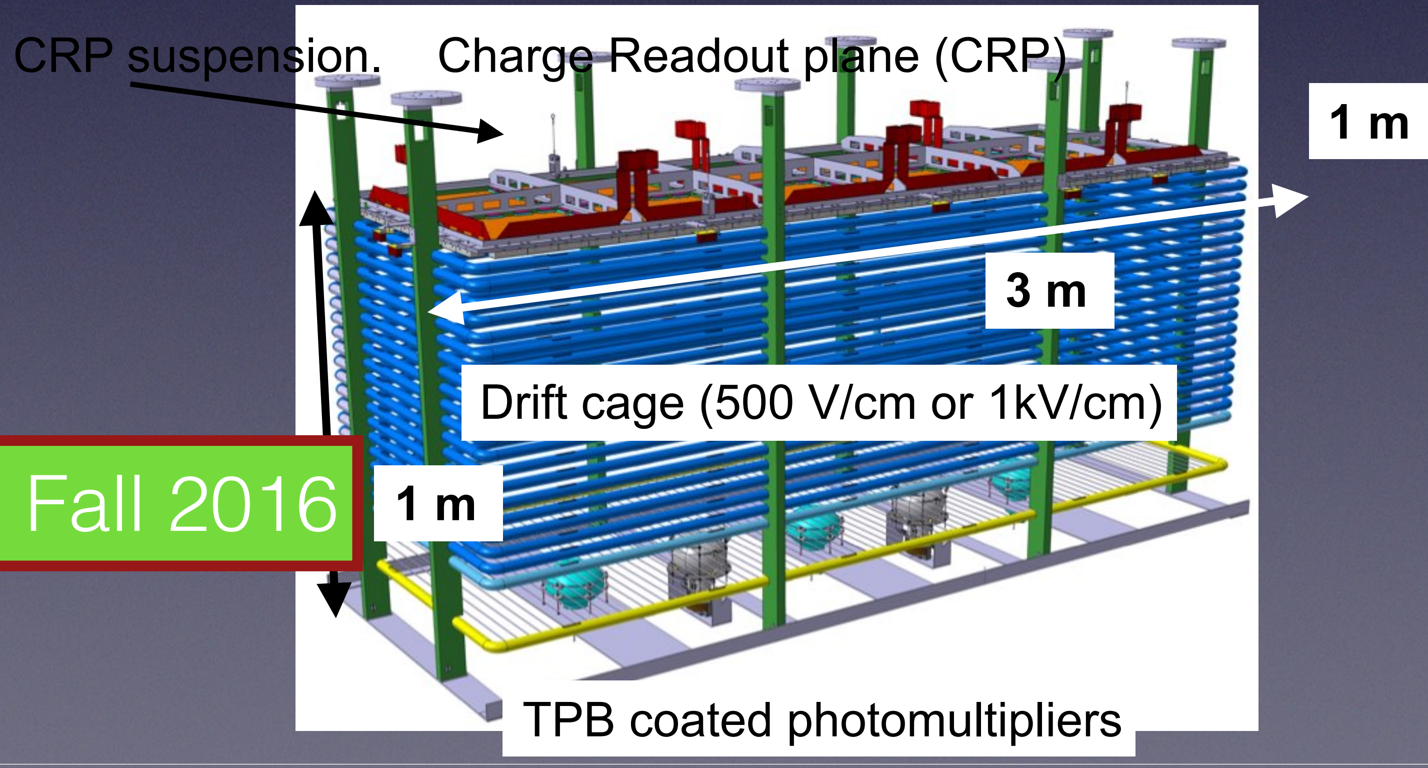
talk Sara Bolognesi

WA105 3x1x1 m3 dual phase TPC



Leak check Membrane:

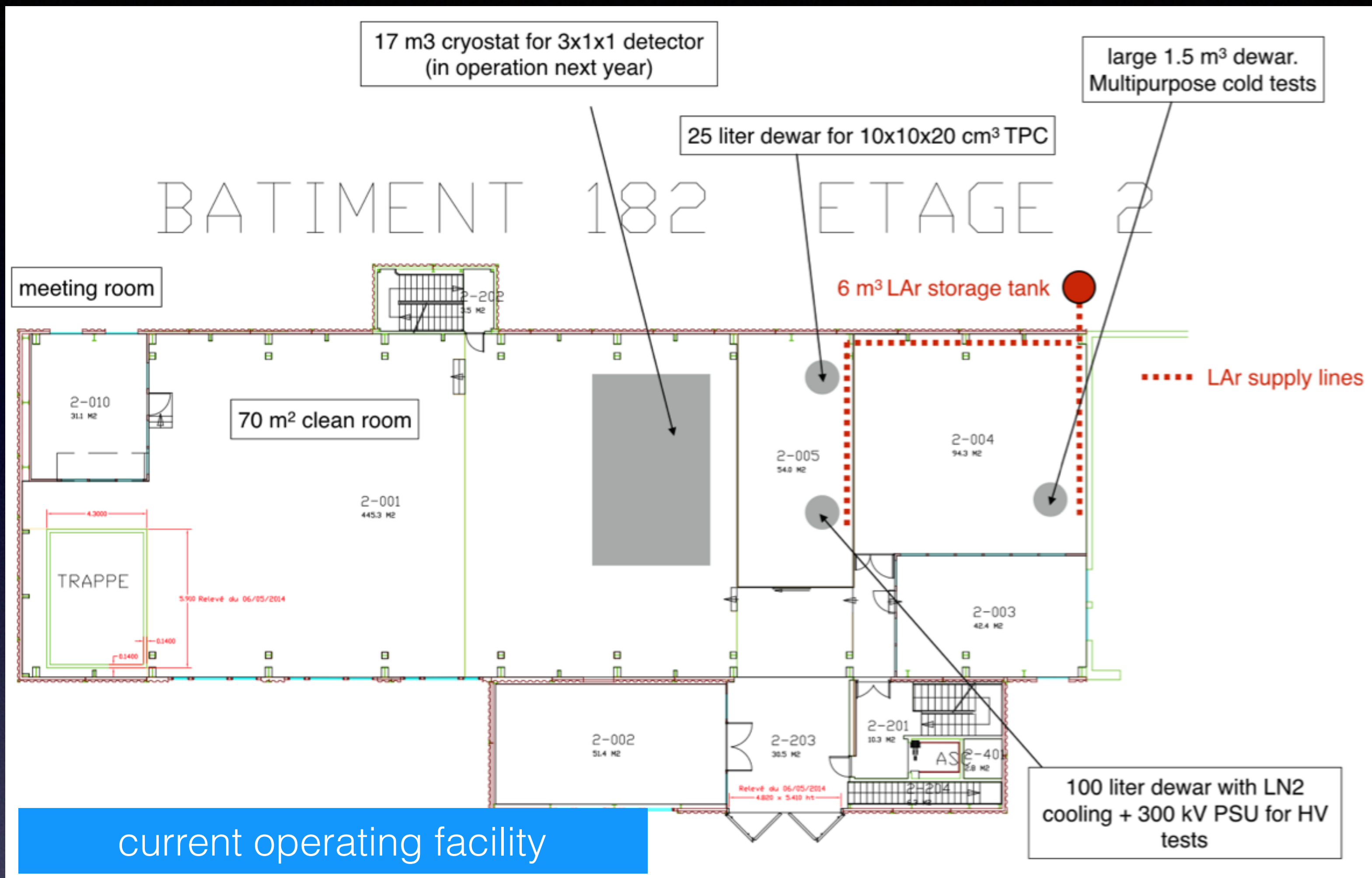
i. GABADI & CEGELEC→ sensitive to 1e-5 (mbar l/s)
ii. CERN is improving the test in order to reach 1e-9 (mbar l/s)

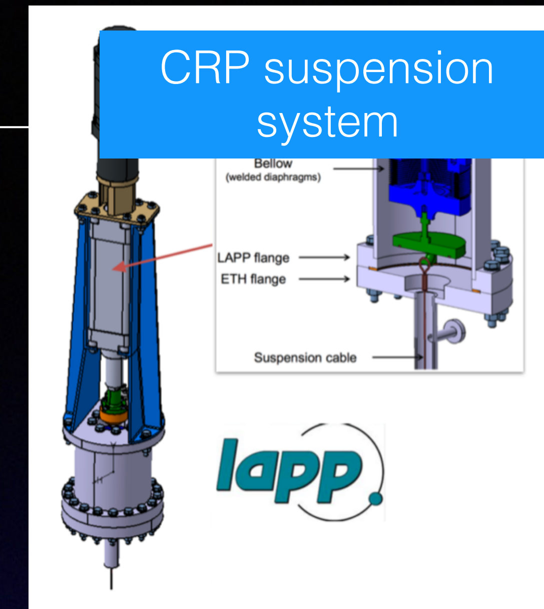


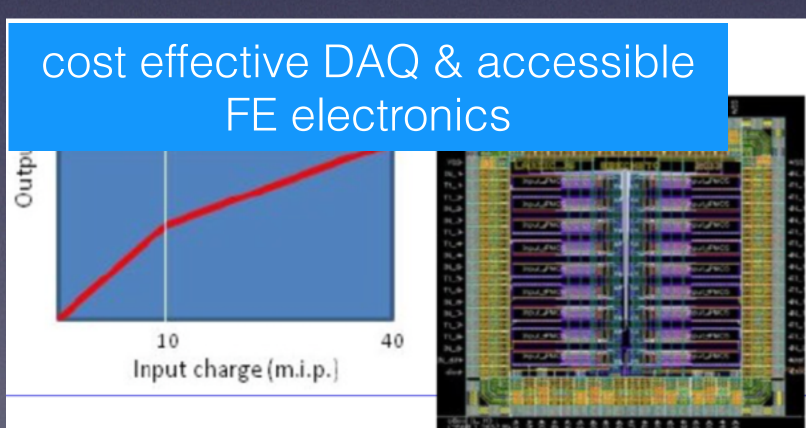
- First large scale of dual phase TPC
  - 25 ton total LAr mass
  - Active mass 4.2 tons
  - 3 mm readout pitch
  - 2 views
  - 1920 readout channels
  - (3+2) 8” PMTs

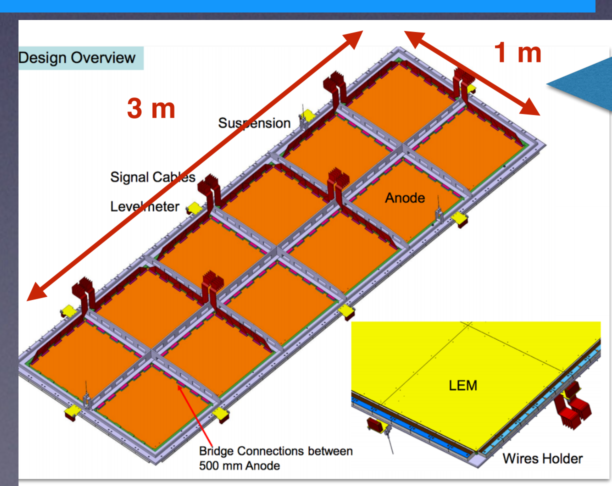
Operational Fall 2016

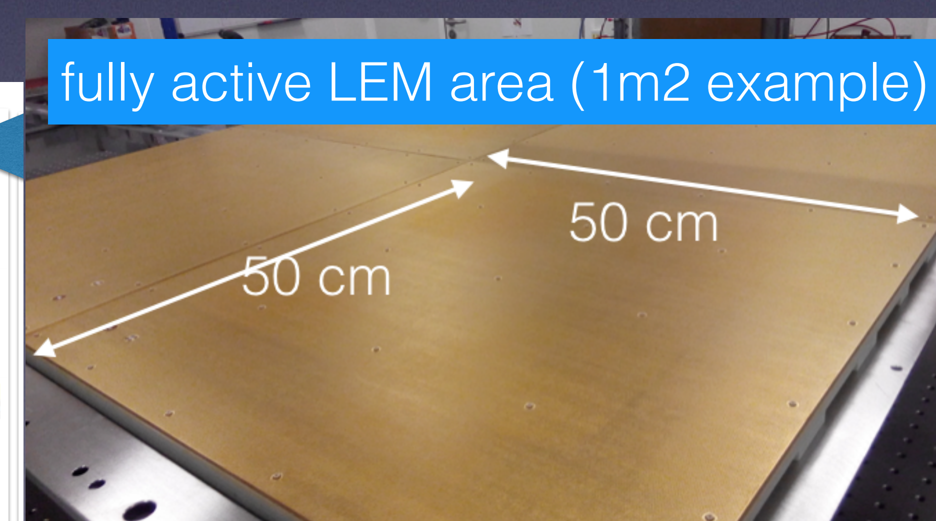
WA105 current prototyping







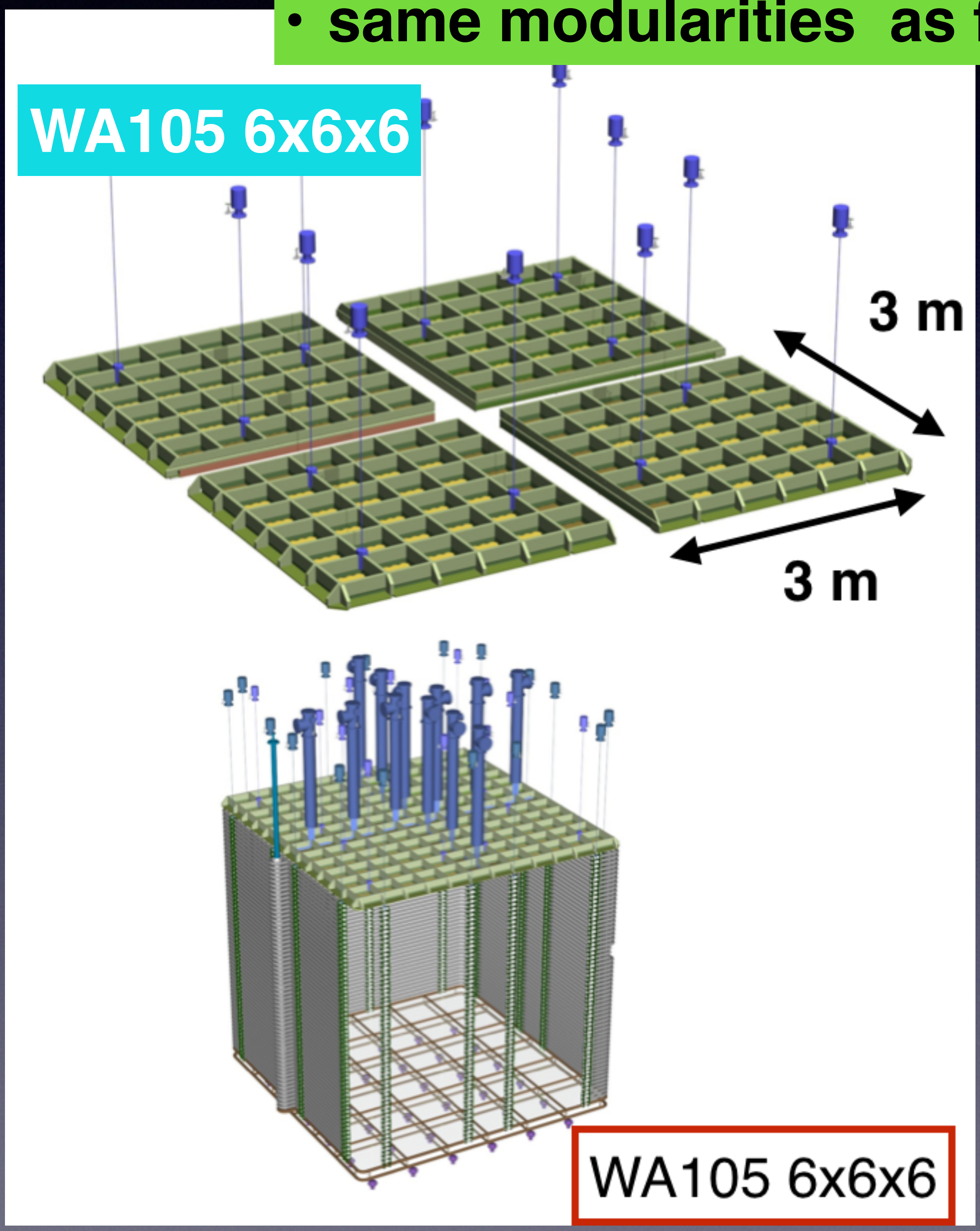


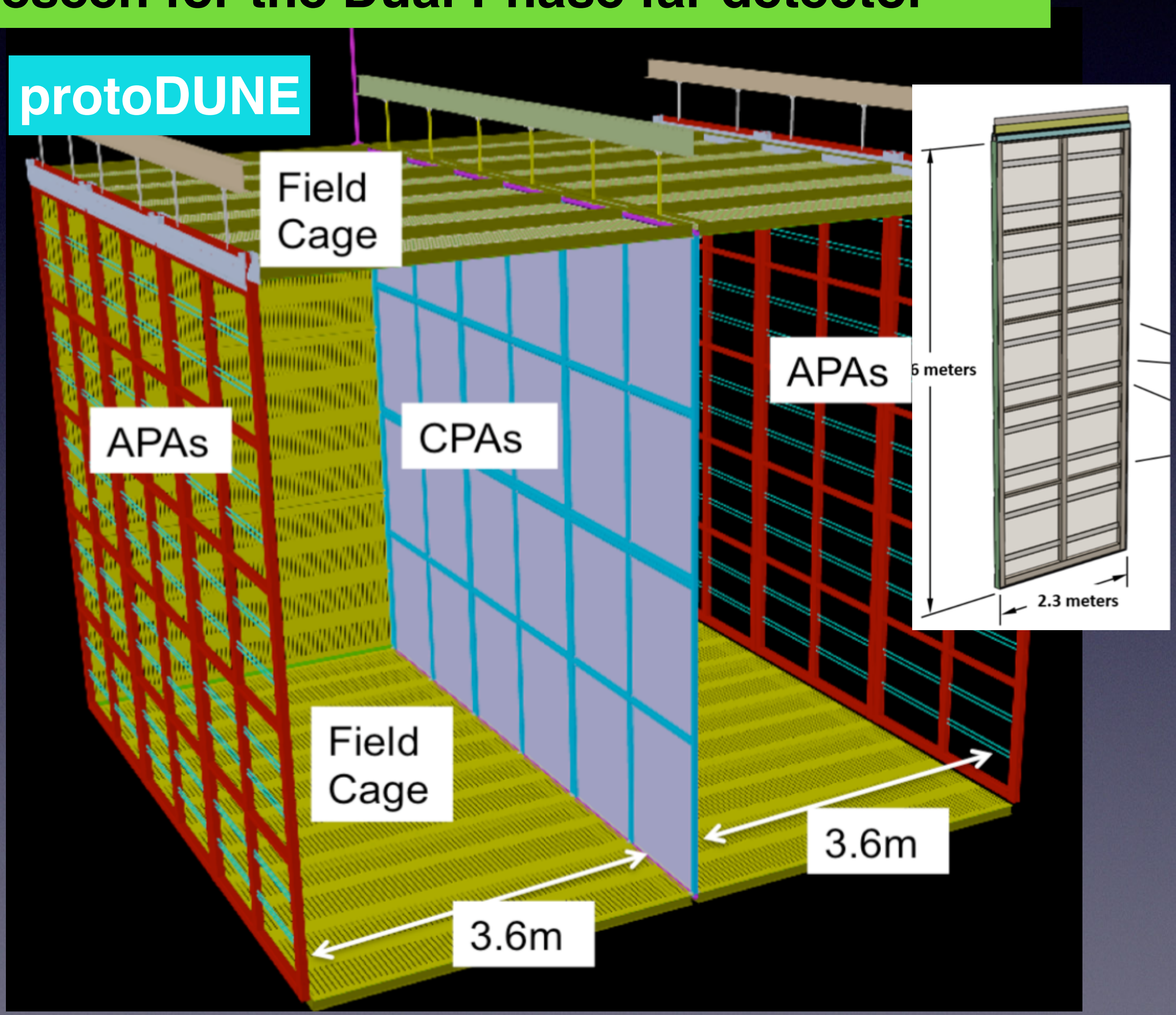


DUNE FD prototyping at CERN

Testing all components designed for the DUNE far detectors at the appropriate scale.

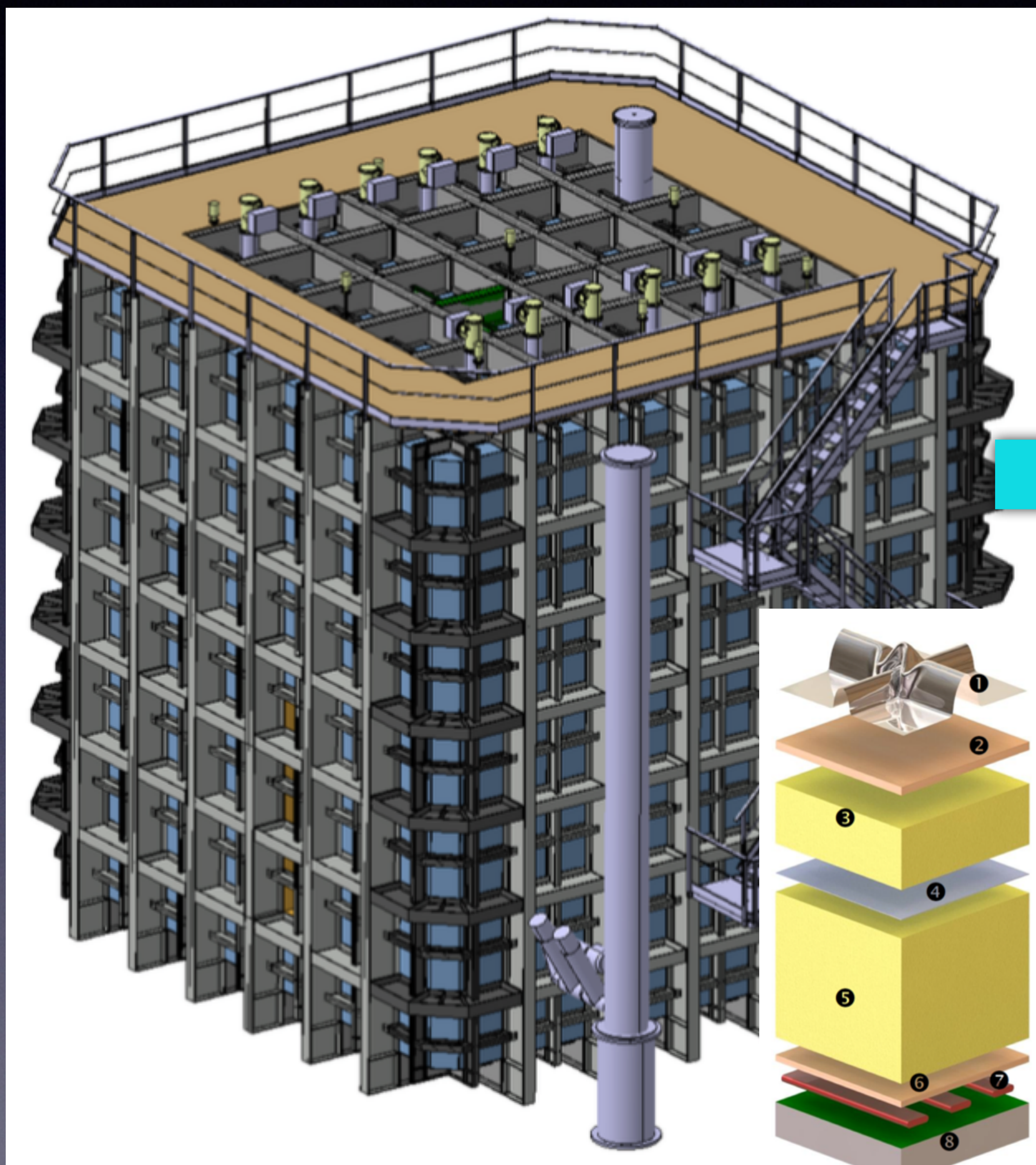
- **same modularities as foreseen for the Dual Phase far detector**

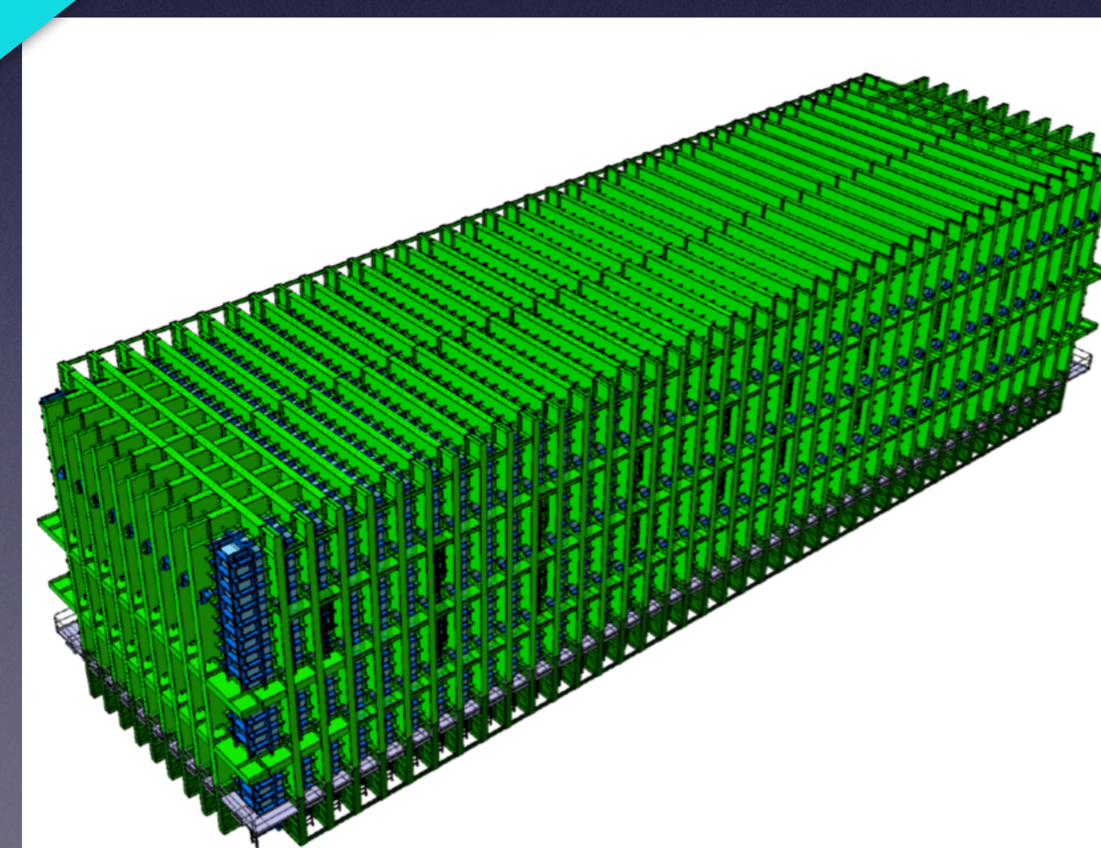




DUNE FD prototyping at CERN

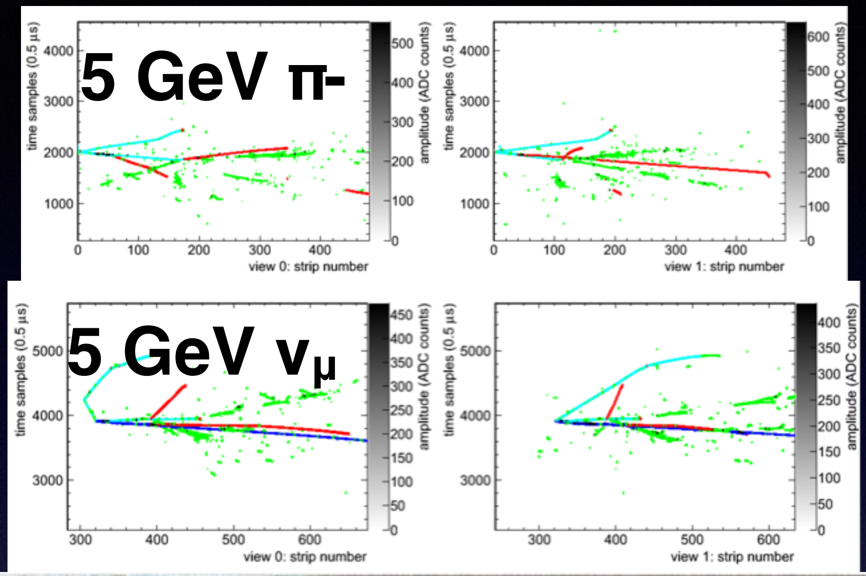
Testing the GTT cryostats

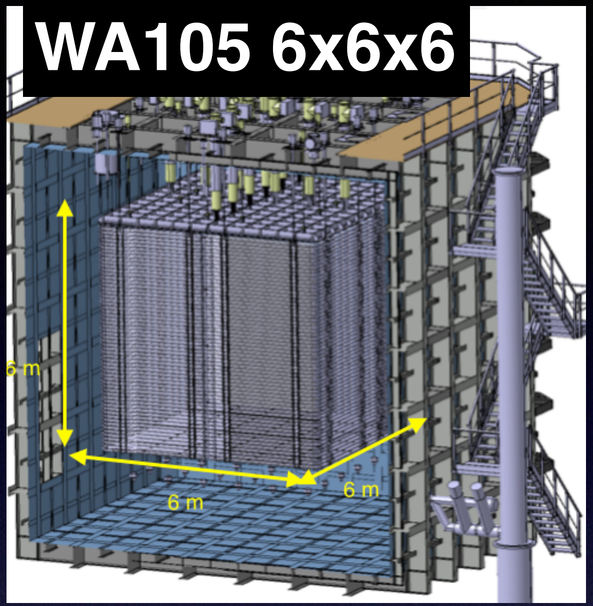


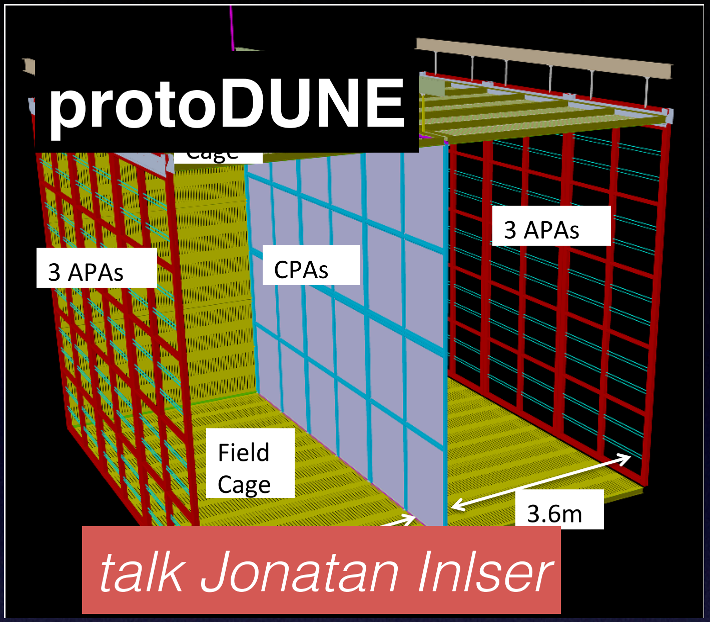


Prototyping at CERN: test beam area extension

pions, electrons/positrons, protons, muons

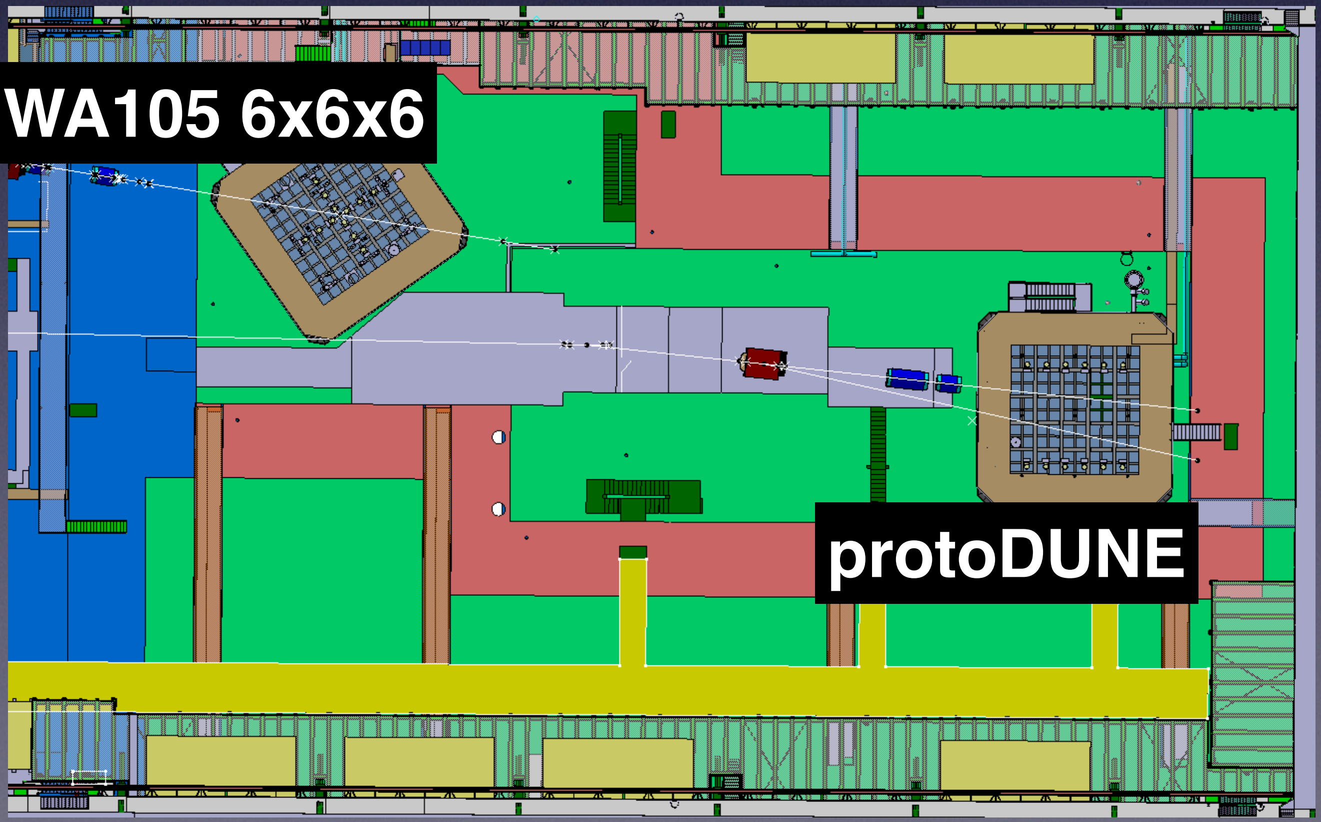






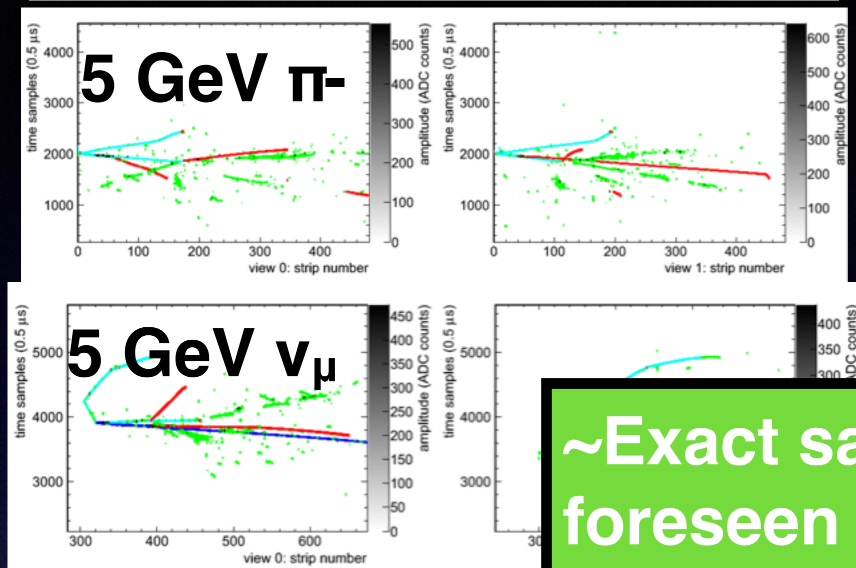
talk Jonatan Inlser

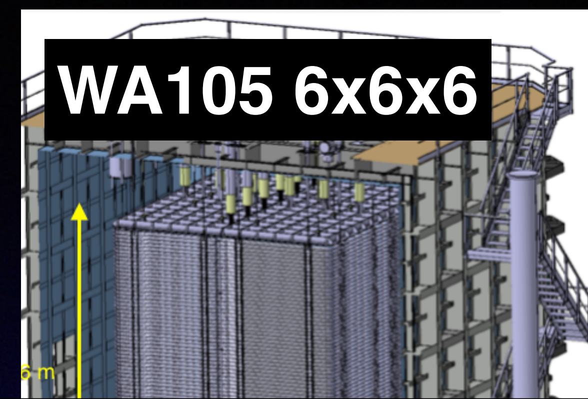
Running ~ 2018-2019

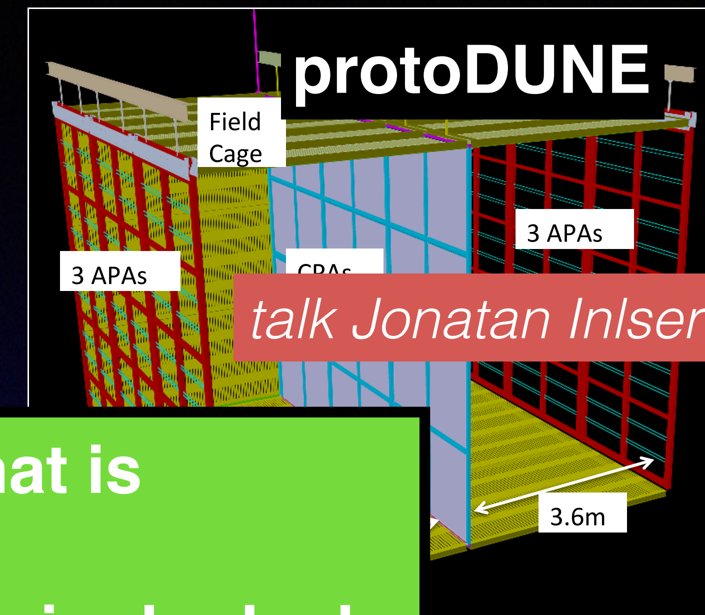


Prototyping at CERN: test beam area extension

pions, electrons/positrons, protons, muons

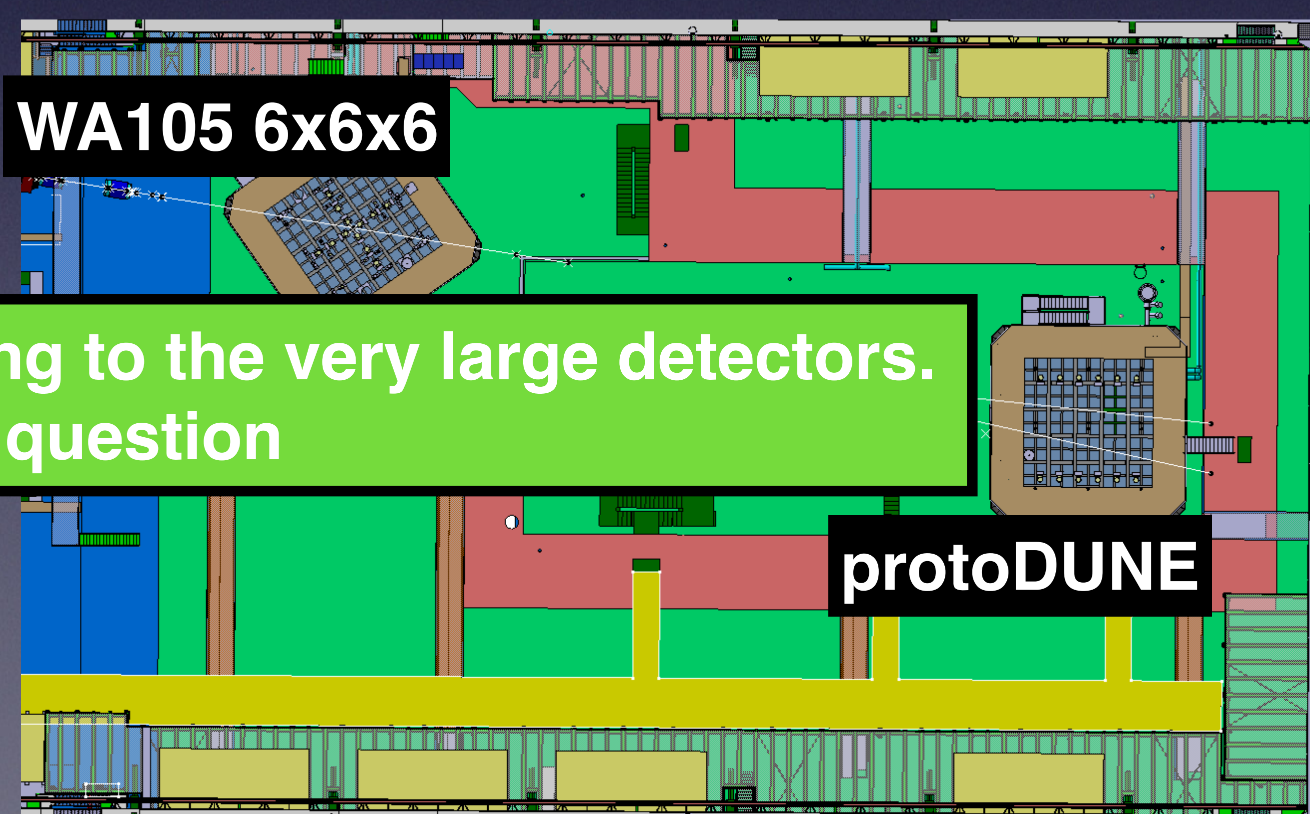






talk Jonatan Inlser

~Exact same detector configuration as what is foreseen for the far detectors.
In a test beam- unique opportunity to test single-dual phase in same conditions

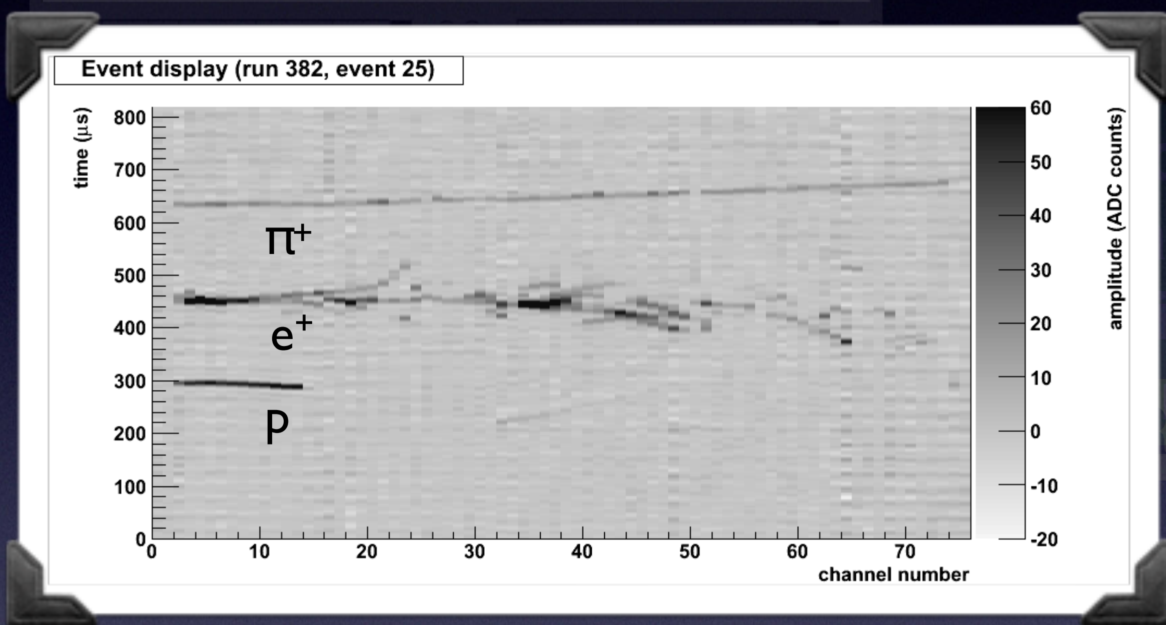


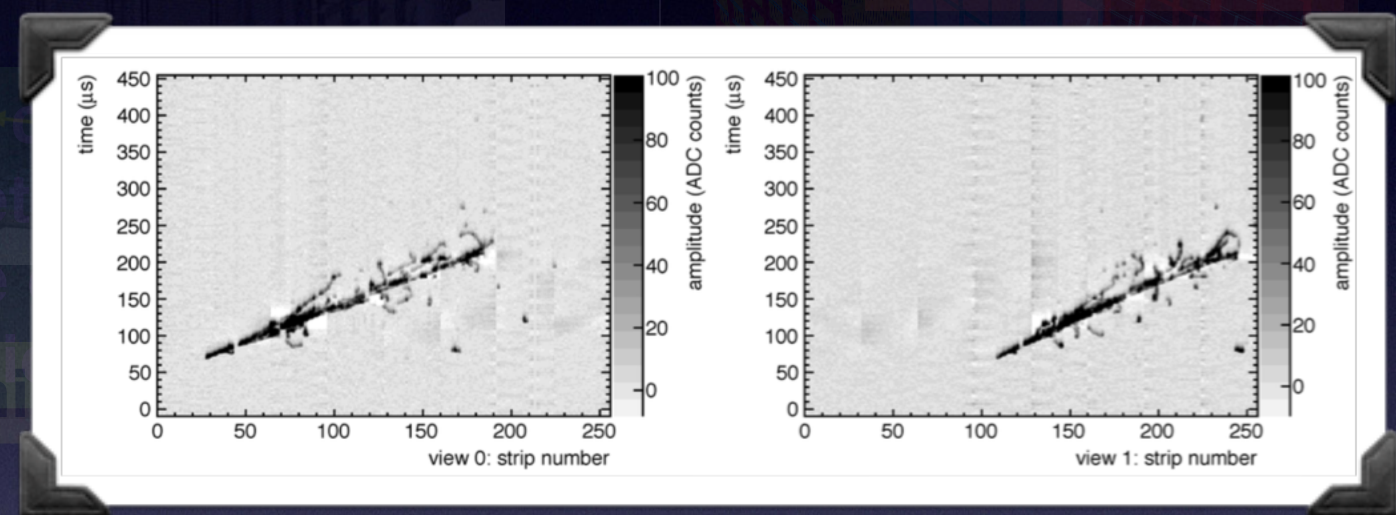
Indispensable step before going to the very large detectors.
Will provide the answer to the question

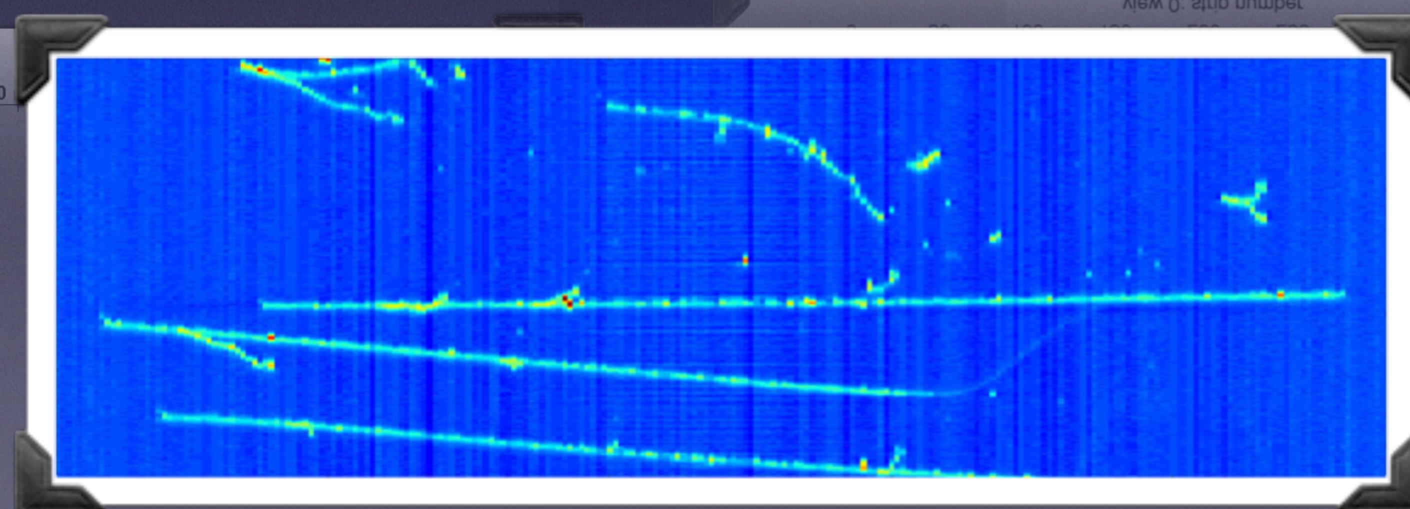
Prototyping at CERN: test beam area extension

pions, electrons/positrons, protons, muons

- **Indispensable step before going to the very large detectors.**
- **Will provide the answer to the question**







1999 - 2015   Large liquid argon detectors

Nucleon decay studies in a large Liquid Argon detector

M.Campanelli

A.Bueno

A.Rubbia

...al open problem

...o possibility can be

...ng is very powerful

...ly essential in case

...d for 10 years the technology to have reliable large mass Liquid Argon TPC for neutrino and nucleon decay physics

- In principle, there are no limitation in reaching very large masses (O(30 kton)) with this technology
- Most of the decay channels are basically background-free, so the sensitivity grows linearly with exposure and mass
- Nucleon decay requires patience... hopefully not infinite.

In principle there are no limitations in reaching very large masses with this technology

NNN99 Workshop

...orkshop on Next Generation Nucleon Decay and Neutrino Detector -

\- September 23-25, 1999 -

...University of New York at Stony Brook -

NNN99

nnn99@superk.physics.sunysb.edu

...t modified: Wed Oct 27 18:05:57 EDT 1999

Second Bulletin i... format

Registration

Scientific Progra...

Working Groups

Transparency Sca... construction)

Photo taken d... workshop (un...

Proceedings I... construction)

Social Events

Workshop Comm... Committee Members

The poster for the workshop in PDF, PS format.

General Information

- Venue
- Directions
  - By plane
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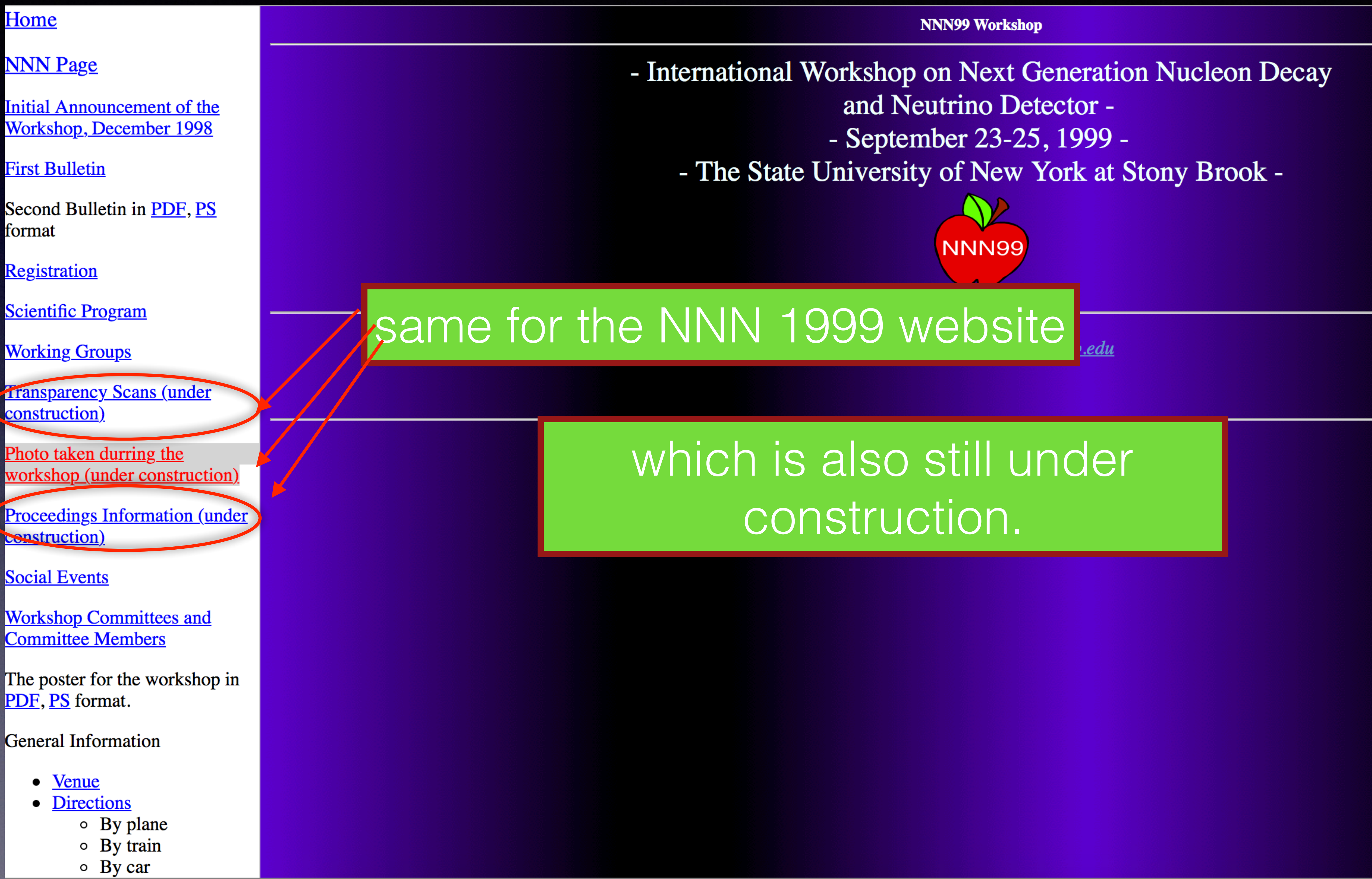
In principle there are no limitations in reaching very large masses with this technology

16 years later

Still haven't constructed it but the goals are now well defined, the interest is continuously growing and the progress is accelerating.

1999 - 2015 Large liquid argon detectors



same for the NNN 1999 website

which is also still under construction.

1999 - 2015   Large liquid argon detectors

unarguably constructing such detectors takes time….

We are getting there

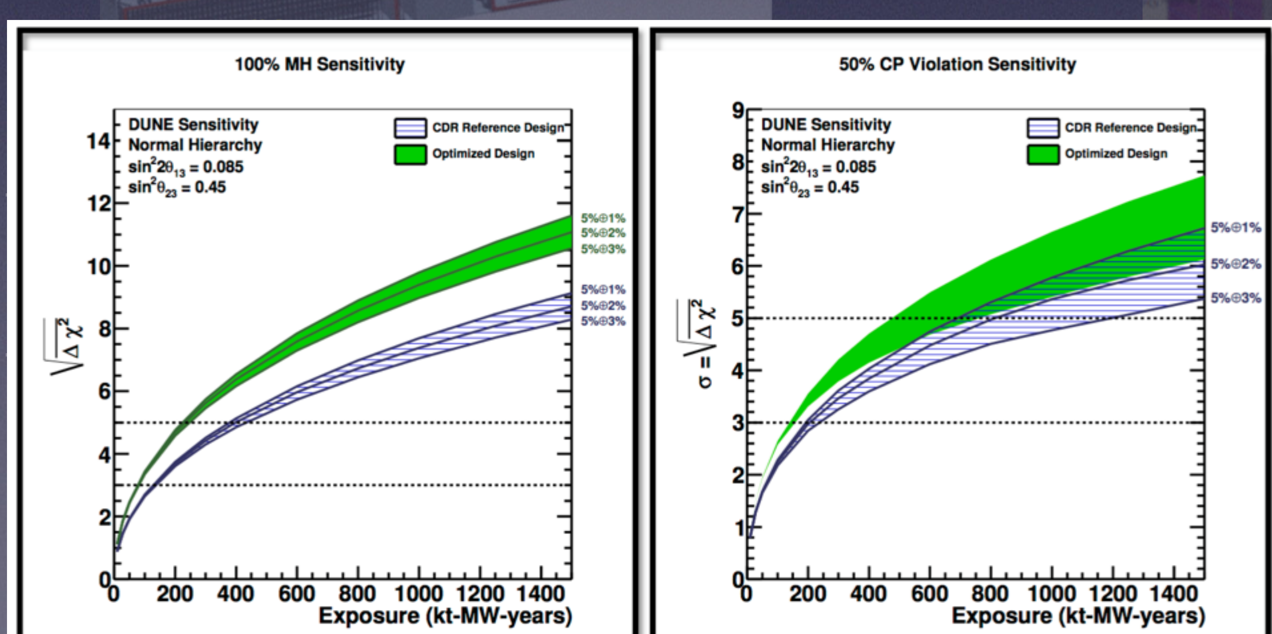
the goals are now well defined.
And remember:
“He who hesitates is lost.”


THANK YOU!
and see you at Stony brook for NNN 2031


EXTRA SLIDES

Long baseline neutrino program

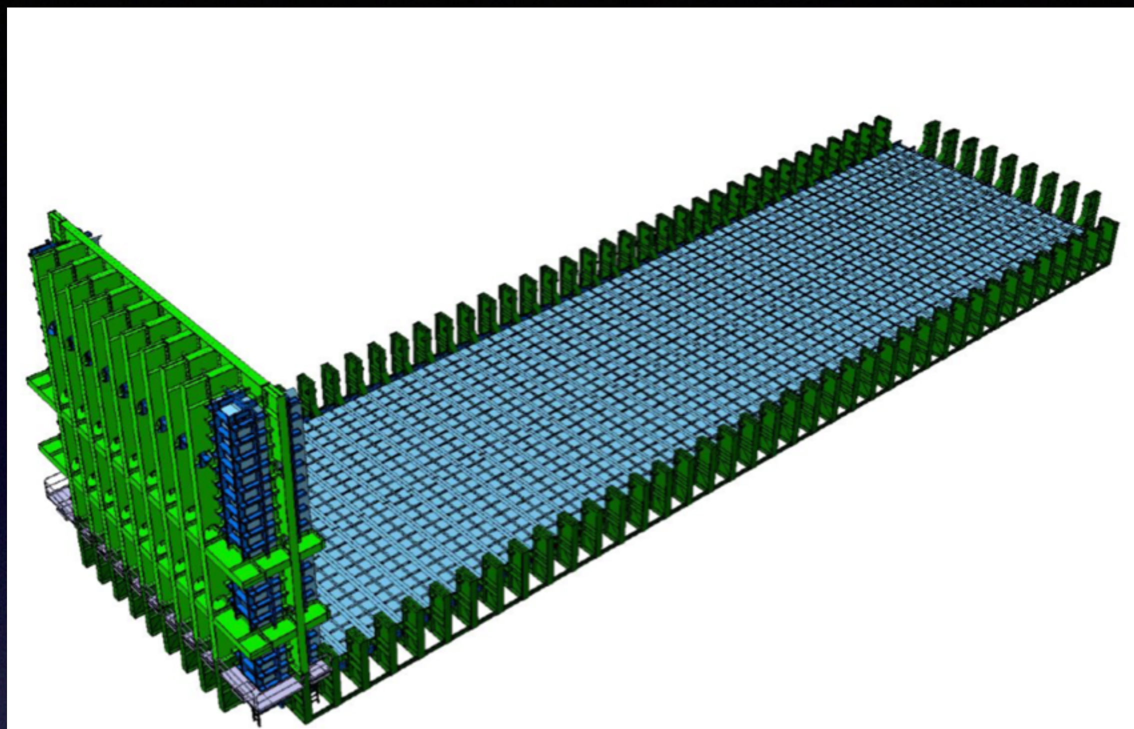
- ✓**Measurement of CP-violating phase** (δ_{CP}) P5 goal of 3 sigma coverage of 75% of δCP phase space by 850-1300 kt-MW-years.
- ✓**5 sigma sensitivity to mass hierarchy** for all values of δCP by 400 kt-MW-years
- ✓**proton decay** (~4×10^{35} p->Kν => increase current limits of an order of magnitude)
- ✓**supernovae neutrino detection** (o(10'000) neutrino SN explosion @10kpc)
- ✓**and also:** precision measurement of neutrino oscillation parameters, test of 3-neutrino paradigm, nu_tau appearance, atmospheric neutrinos, precise x-section measurements in near detector,…

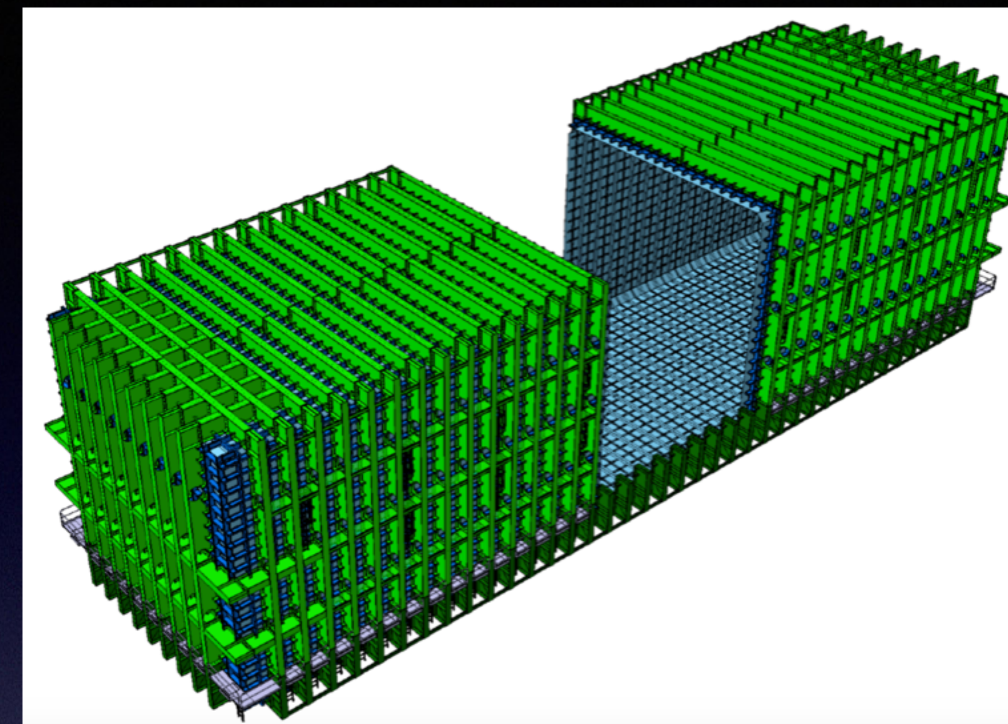


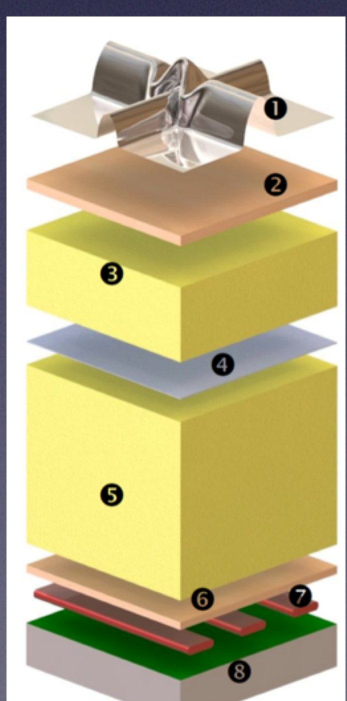
talk Elizabeth Worcester

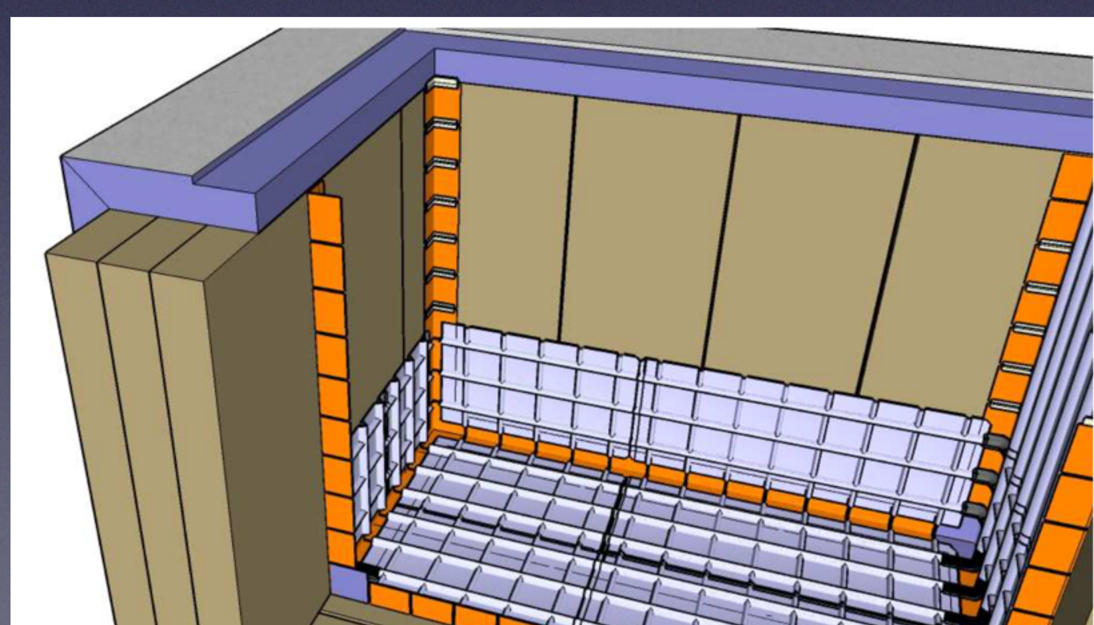
Decay Mode	Water Cherenkov		Liquid Argon TPC	
	Efficiency	Background	Efficiency	Background
$p \rightarrow K^+\overline{\nu}$	19%	4	97%	1
$p \rightarrow K^0\mu^+$	10%	8	47%	< 2
$p \rightarrow K^+\mu^-\pi^+$			97%	1
$n \rightarrow K^+e^-$	10%	3	96%	< 2
$n \rightarrow e^+\pi^-$	19%	2	44%	0.8

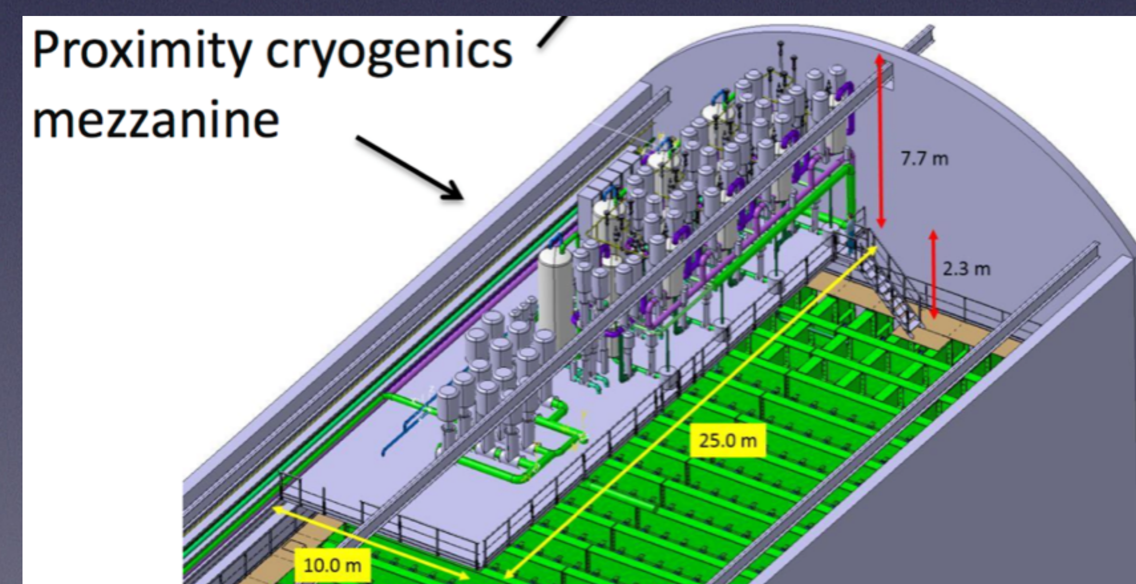
And for some construct them underground











Starting up MicroBooNE and pimping up ICARUS

From Pavia to LNGS (2004)

From LNGS to CERN (2014)

in the clean room @ CERN

- T600 is being upgraded at CERN (WA104) introducing technology developments **while maintaining the already achieved performance:**
  - new cold vessels (purely passive insulation);
  - refurbishing of cryogenics/purification equipment;
  - a cathode with better planarity;
  - upgrade of the light collection system;
  - new faster, higher-performance read-out electronics.

talk Alessandro Menegolli

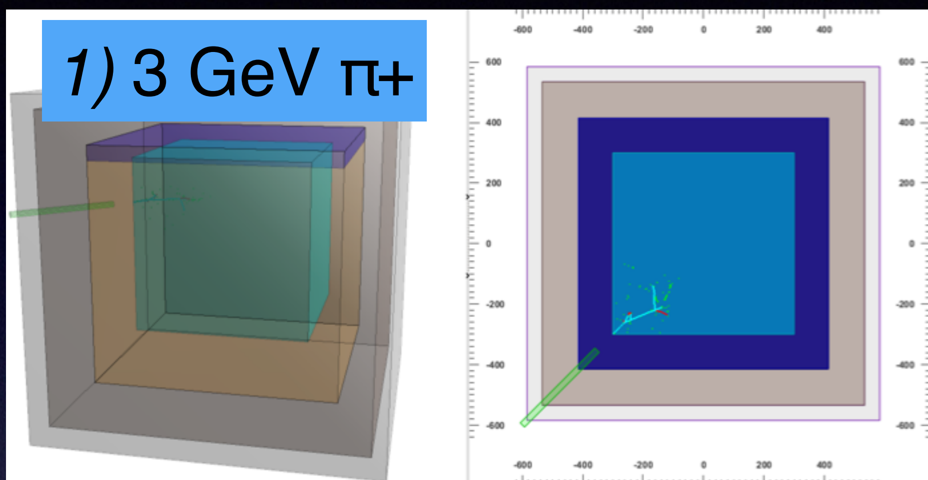
- **The T600 detector is expected be moved to FNAL within the end of 2016, to start data taking by end 2017 with the Booster Neutrino Beam.**

Reconstruction of LAr events

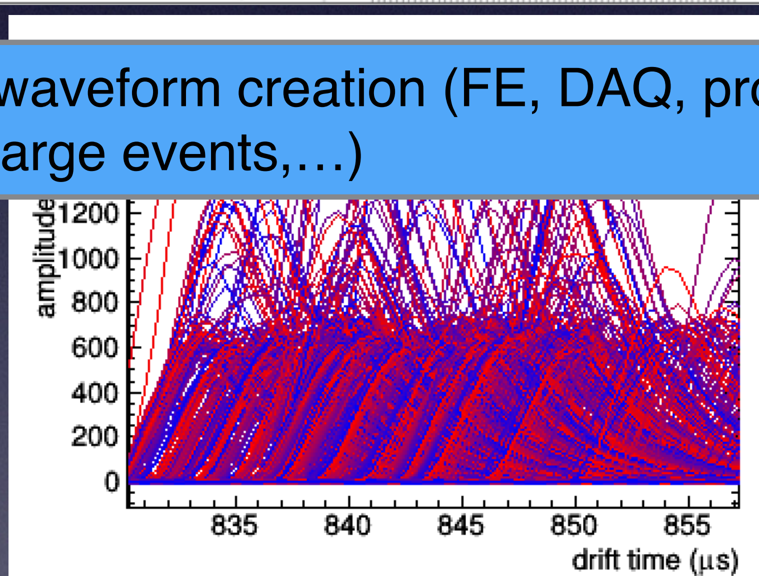
RAW-DATA

clustering and 3D matching.
High level algorithms

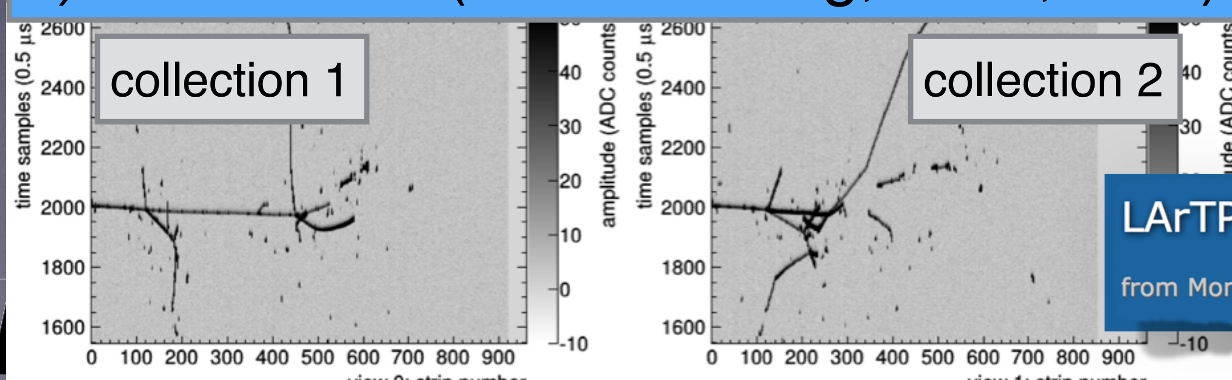
1) 3 GeV π+



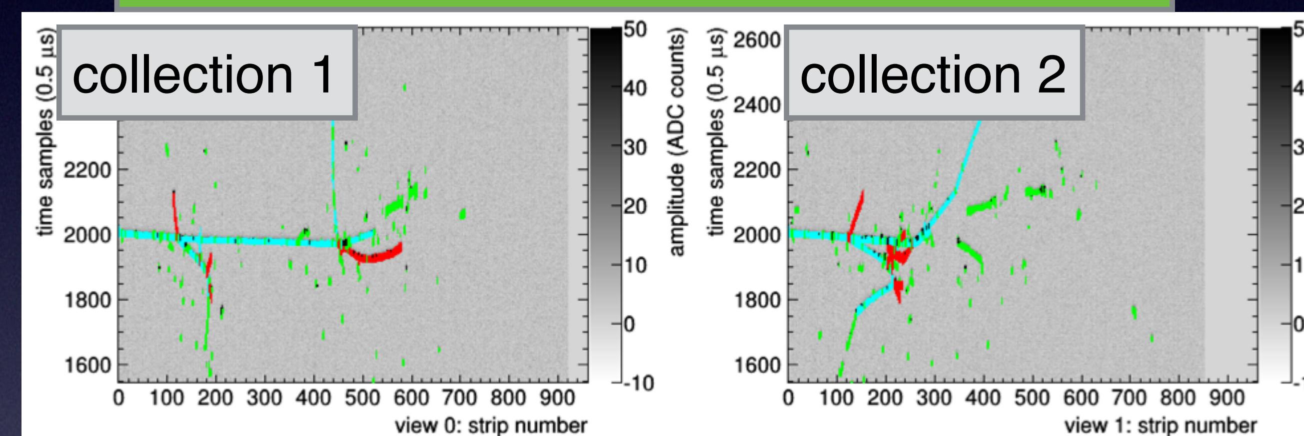
2) waveform creation (FE, DAQ, processing of large events,…)



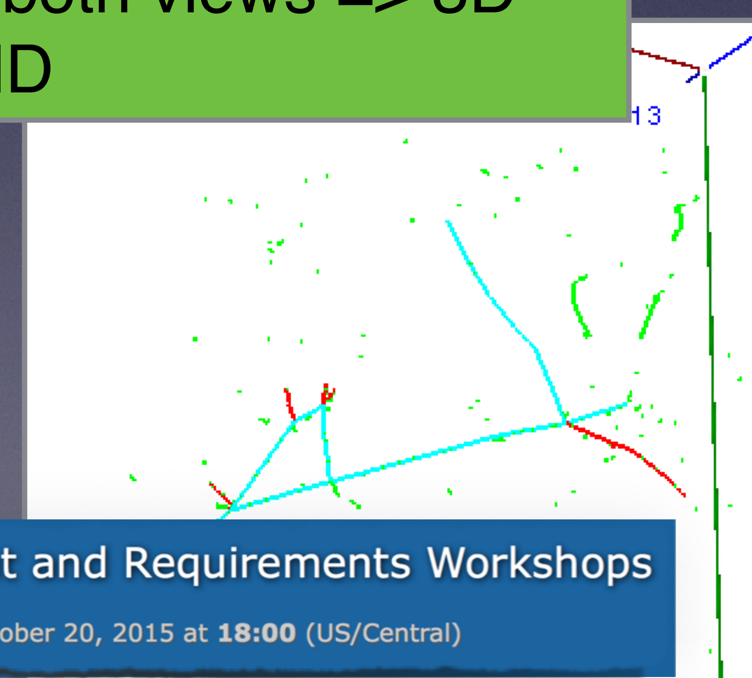
3) hit creation (noise filtering, hit id, etc..)



4) clustering, 2D reconstruction, …



5) merging both views => 3D reco and PID



LArTPC Reconstruction Assessment and Requirements Workshops

from Monday, October 19, 2015 at **08:00** to Tuesday, October 20, 2015 at **18:00** (US/Central)

The current situation

a lot has happened in the last year:

Winter 2014:

- new Collaboration (ELBNF) was with the goal of leading the detector and physics effort (~145 institutions involved)
- Creation of the CERN Neutrino platform.

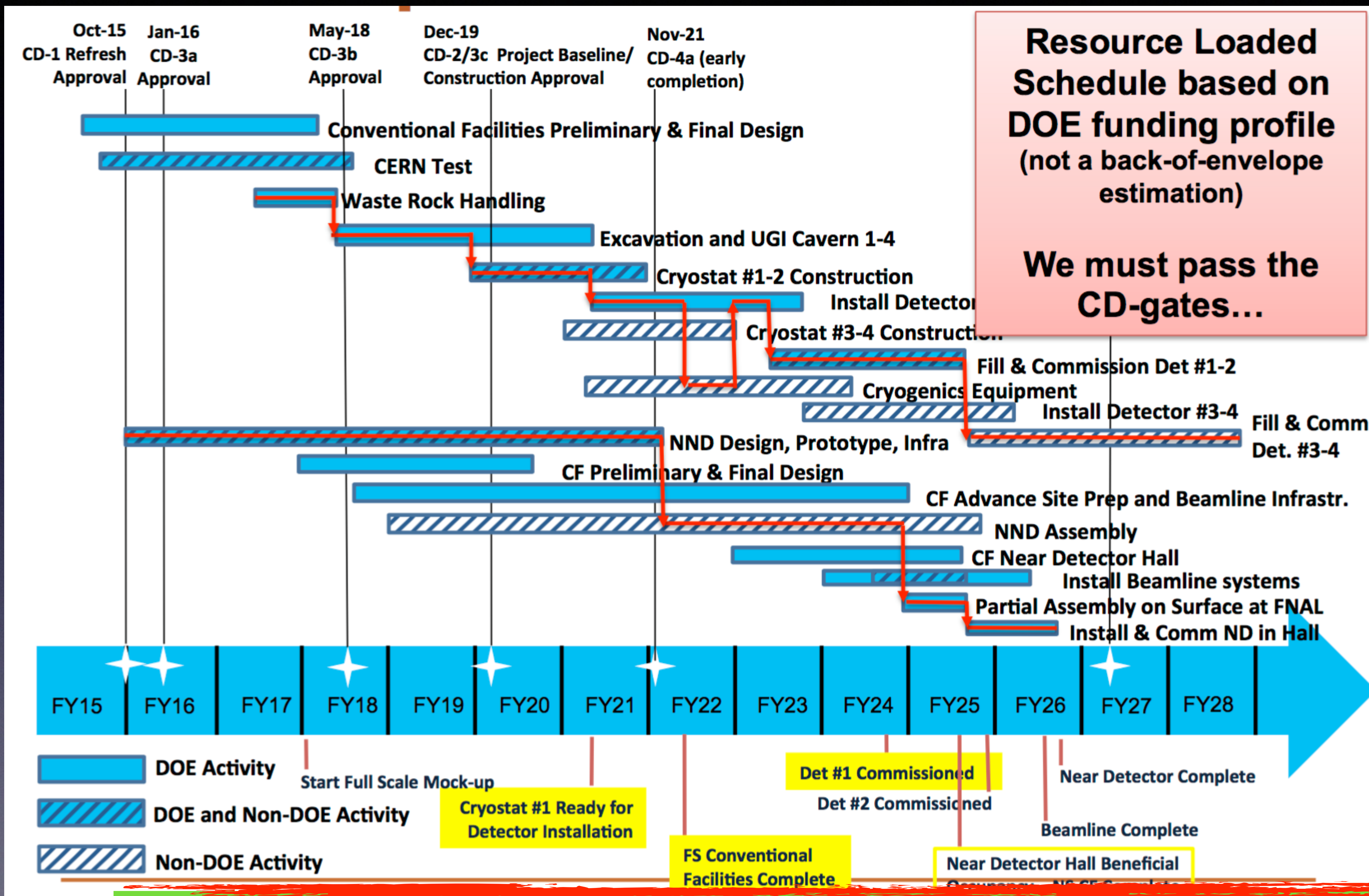
January 2015:

- **Presentation of a CDR on a Short Baseline Program at the FNAL Booster**

Spring 2015:

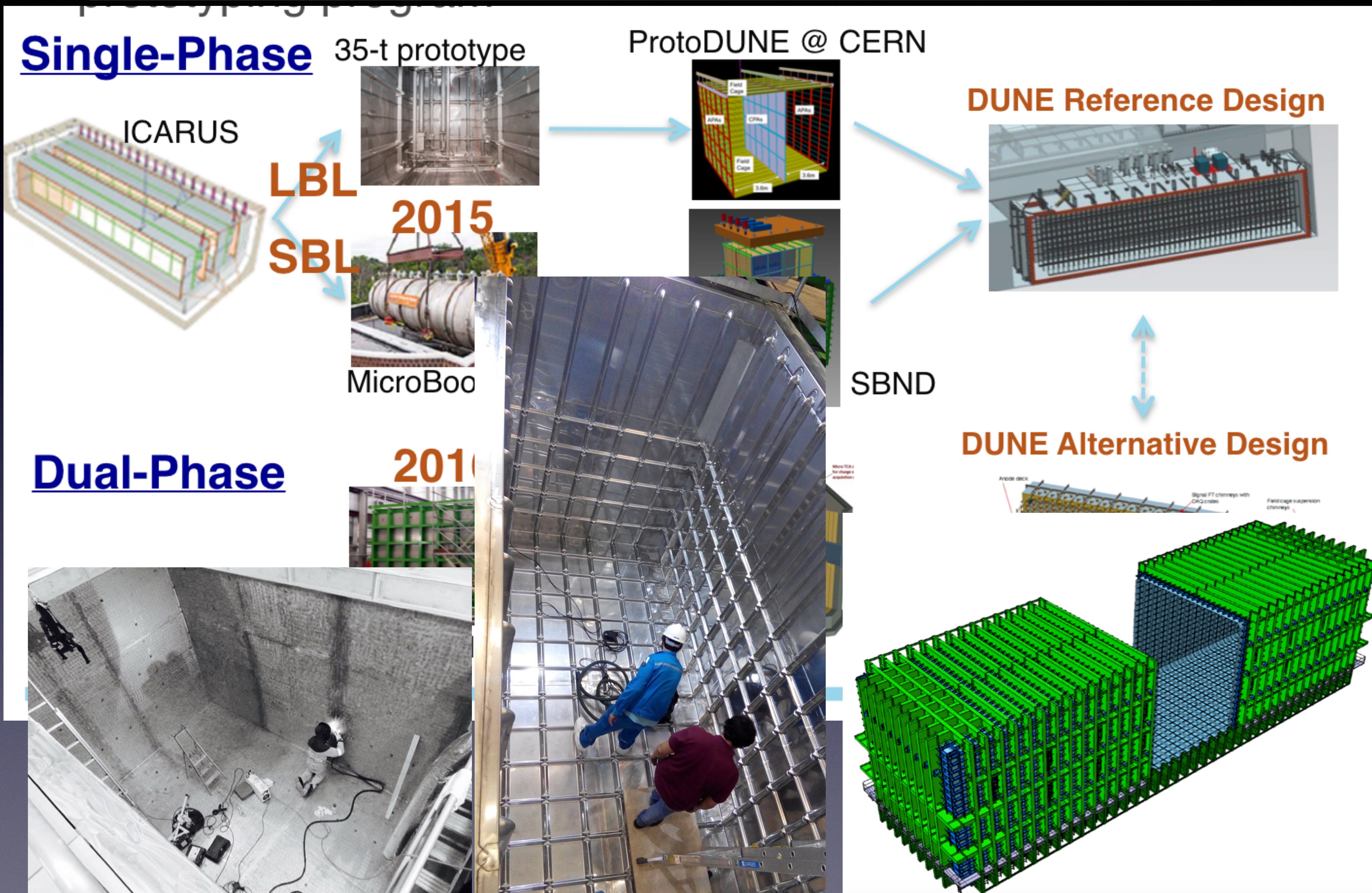
- **creation of the DUNE collaboration. Co-spokespersons elected. First CDR submitted.**
- 16-18 April First DUNE Collaboration meeting
- 2-5 September Second Collaboration meeting

DUNE schedule and critical decisions

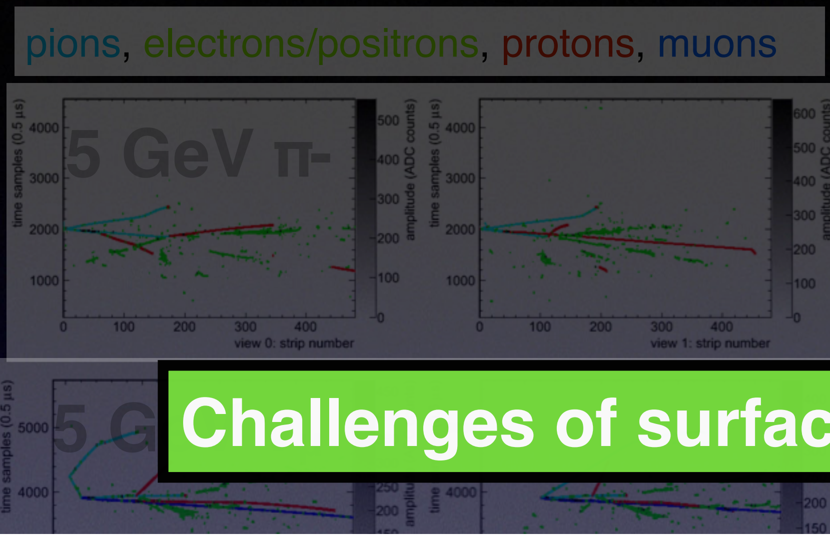


Major discoveries but time is short with many challenges

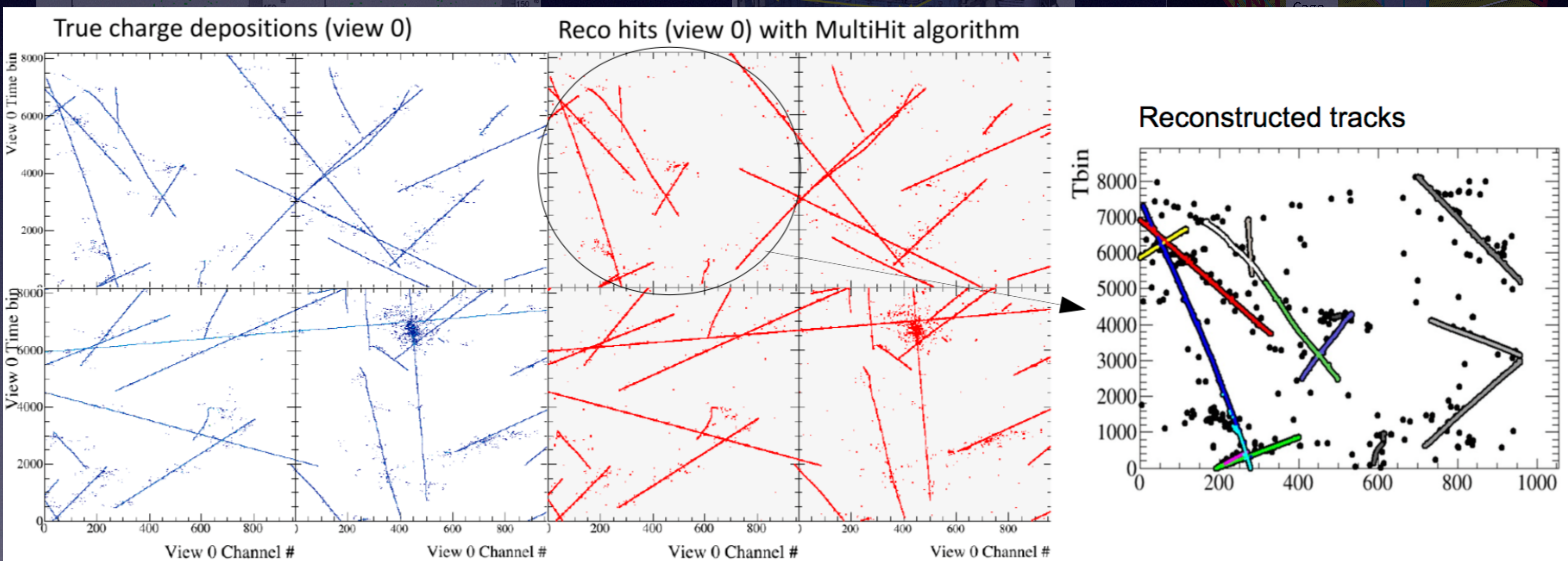
We need to build kton scale cryostats



Prototyping at CERN: test beam area extension



Challenges of surface operation. CERN prototypes and FNAL SBN

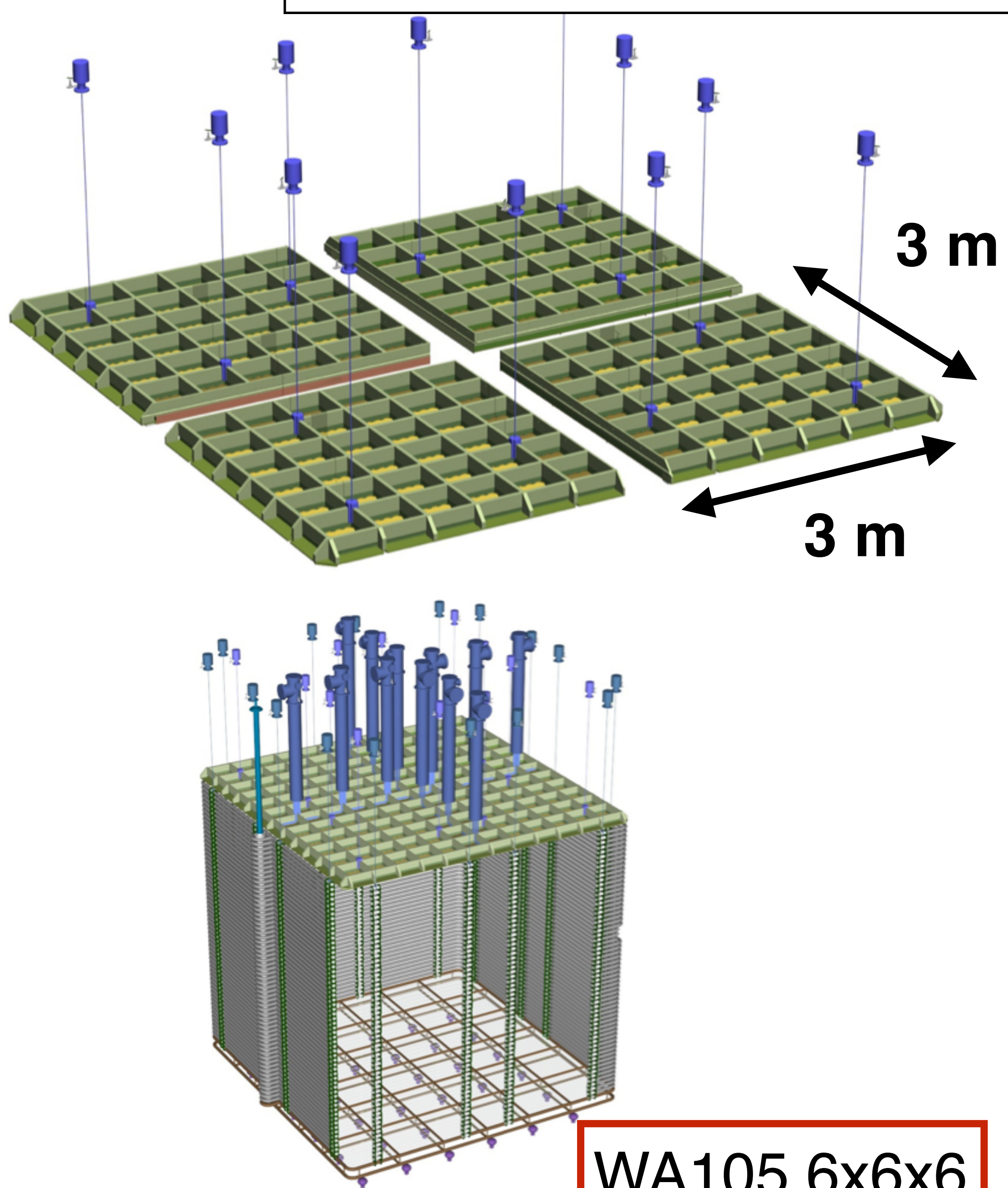


Unique opportunity to test single-dual phase in same conditions

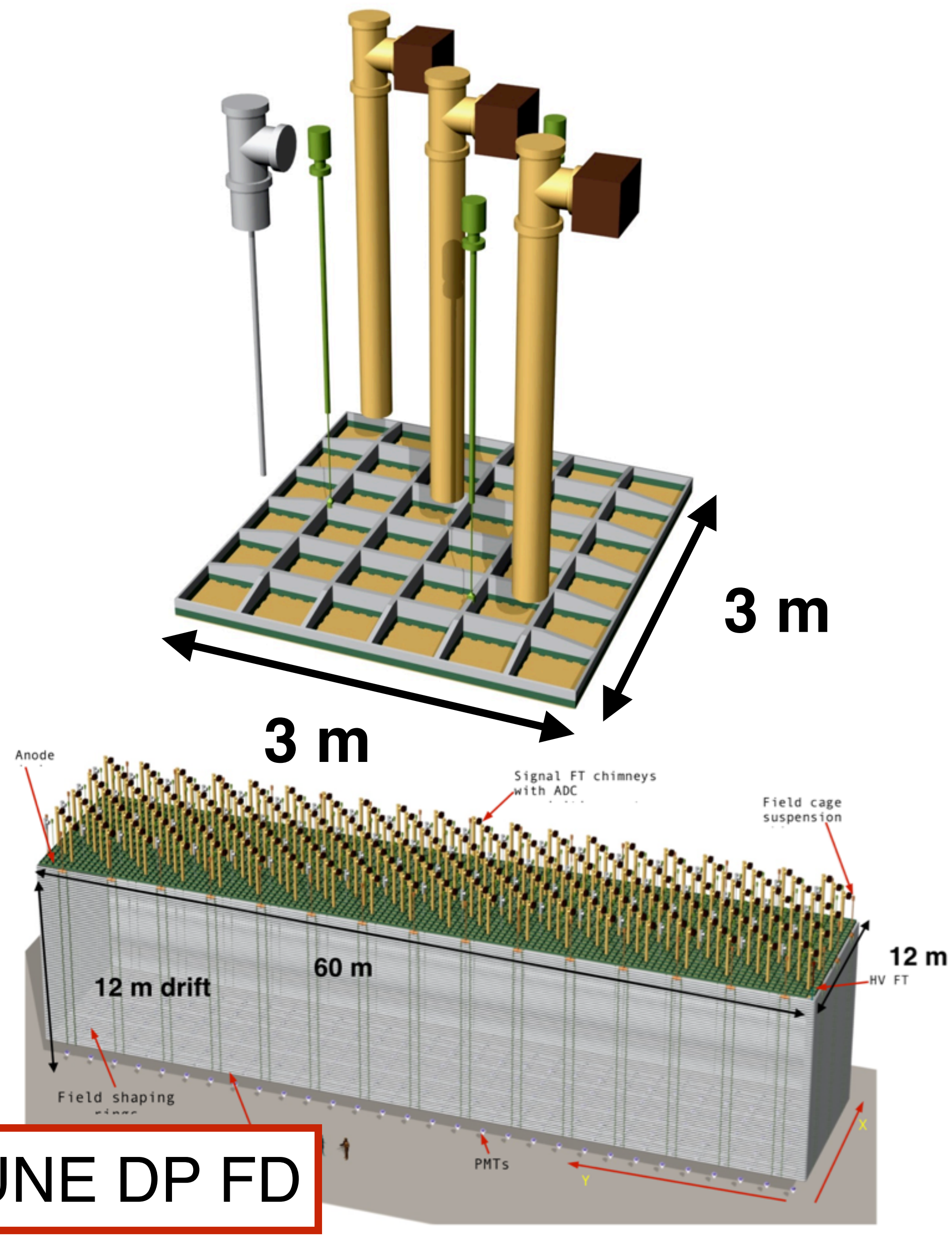
Prototyping at CERN: dual phase

The CRPs come in **4 modules of 3x3 m²:**

- easier for construction and integration
- better mechanical stability
- easier to make cold tests
- **same modules as foreseen for the Dual Phase far detector**

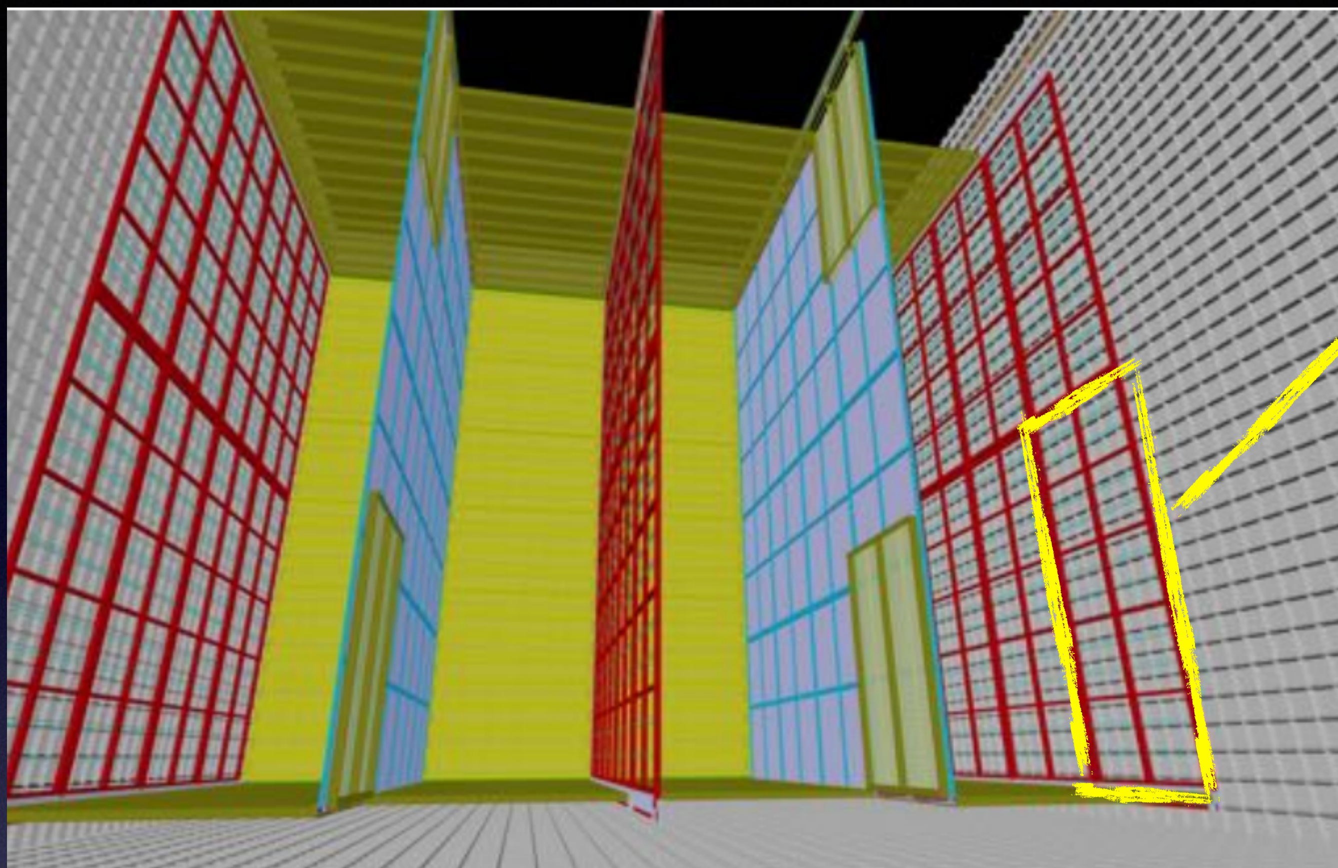


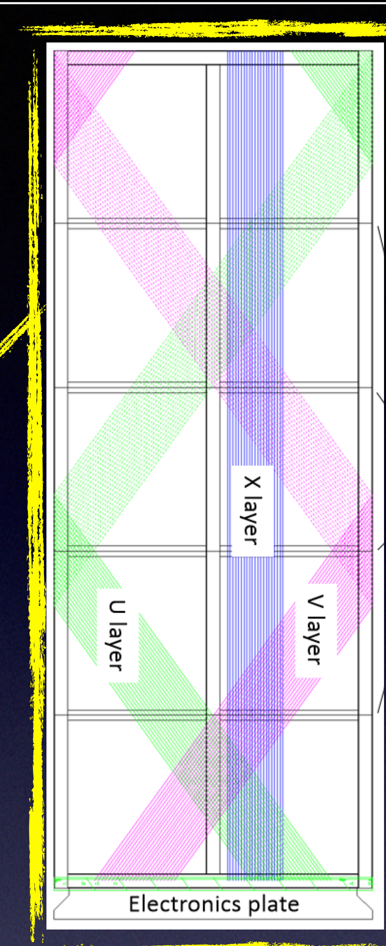
WA105 6x6x6



DUNE DP FD

DUNE far detector - reference design





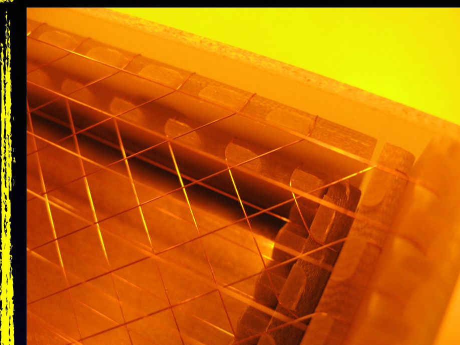


Table 4.2: Parameters of the four planes of wires on an APA

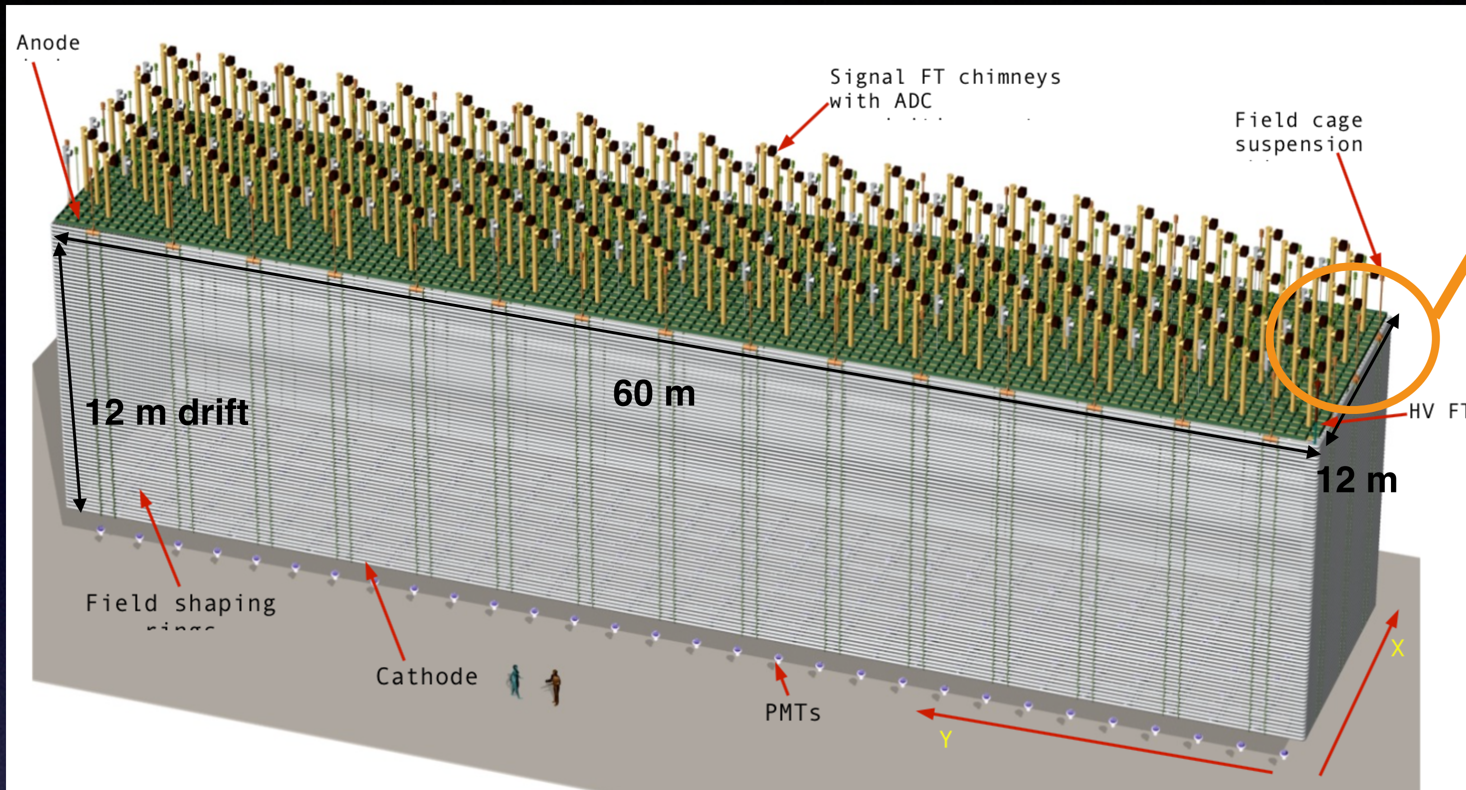
Label	Function	Orientation (from vertical)	Pitch (mm)	Number	Bias Voltage (volt)
G	Shield/grid plane	0°	4.79	960	−665
V	1^{st} induction plane	+35.7°	4.67	800	−370
U	2^{nd} induction plane	−35.7°	4.67	800	0
X	Collection plane	0°	4.79	960	+820

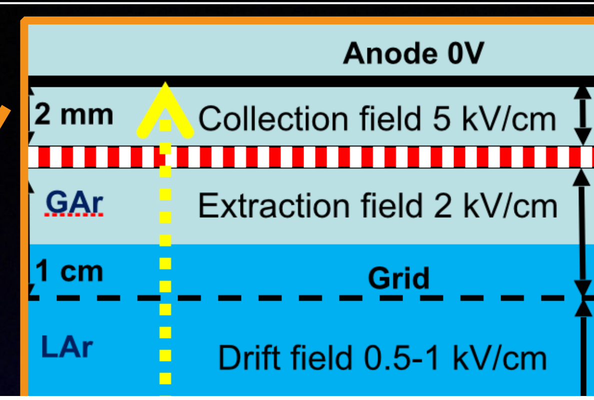
induction 1
induction 2
collection

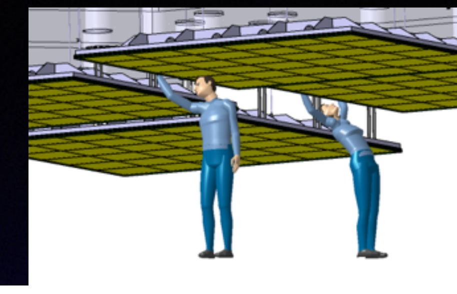
One 10 kt single phase far detector module:

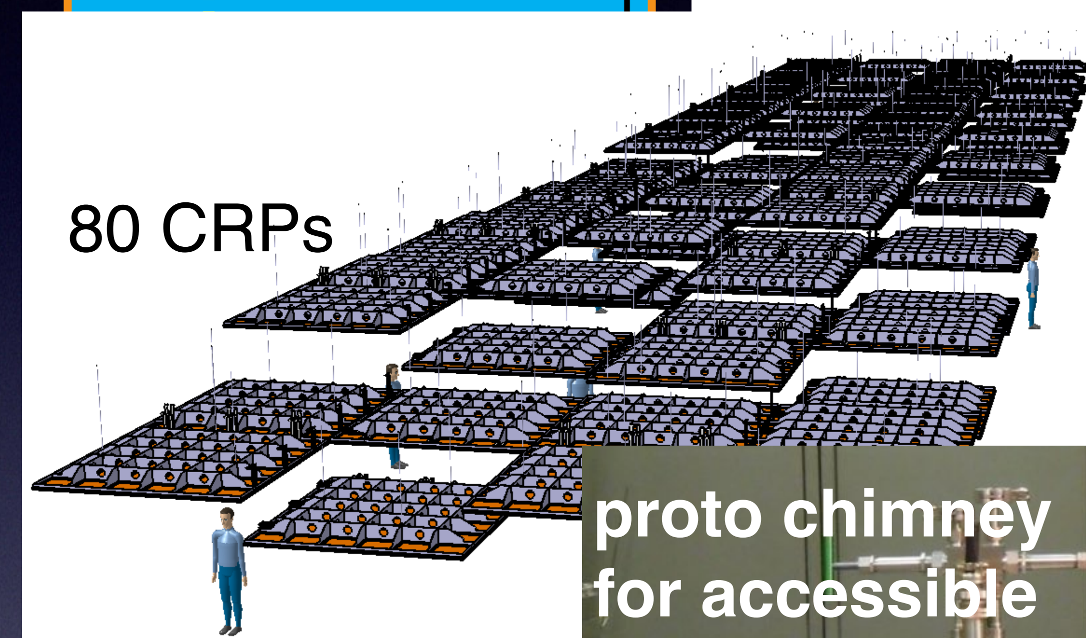
- Active volume: **12m x 14m x 58m**
- 150 Anode Plane Assemblies 6.3m high x 2.3m wide
- 200 Cathode Plane Assemblies 3m high x 2.3m wide
- A:C:A:C:A arrangement
- Cathodes at -180 kV for 3.6m drift
- APAs have wrapped wires – read out both sides
- Each side has one collection wire plane & two induction planes
- 5mm readout pitch

DUNE far detector - alternate design





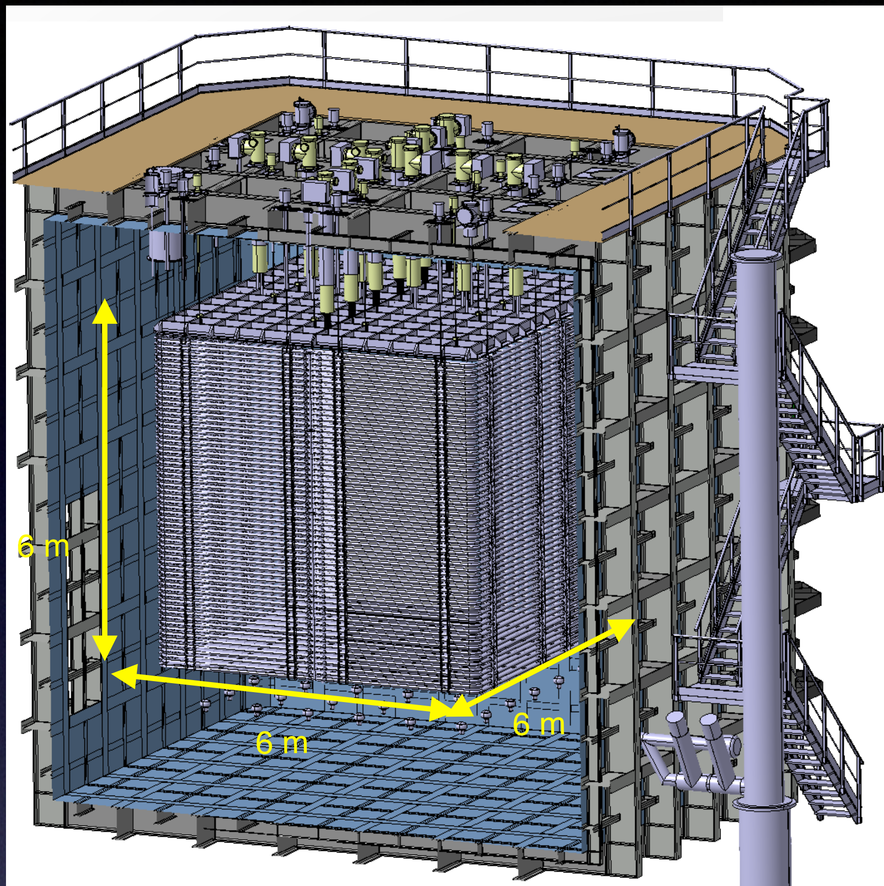




One 10 kt FD module:

- 3x3m2 CRP modules placed at the gas-liquid interface
- 2 perpendicular “collection” views, 3mm readout pitch
- 80 CRPs / 10 kton
- 153,600 ionisation readout channels
- Accessible cold electronics
- Hanging field cage and cathode@600 kV for 0.5 kV/cm
- Decoupled PD system (w/ no. 720 8” PMT)
- Active mass 12’096 tons (10’643 fiducial) for 12m drift

CERN prototyping for DUNE



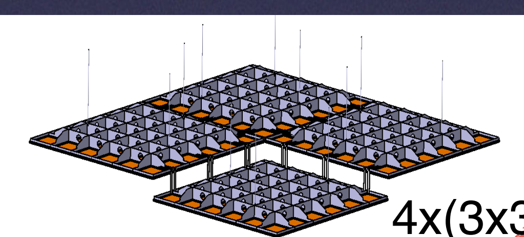
ProtoDUNE and WA105 are the prototypes of the single-phase and dual-phase DUNE far detector designs.

Engineering Prototype Run

- Measure and benchmark detector performance using full-scale detector components
- Develop manufacturing capabilities at multiple sites
- Test installation procedures and operation

Test Beam Run

- Assess detector systematic uncertainties
- Validate and tune MC simulation to data
- Test reconstruction tools and particle ID algorithms
- Study particle interactions



WA105

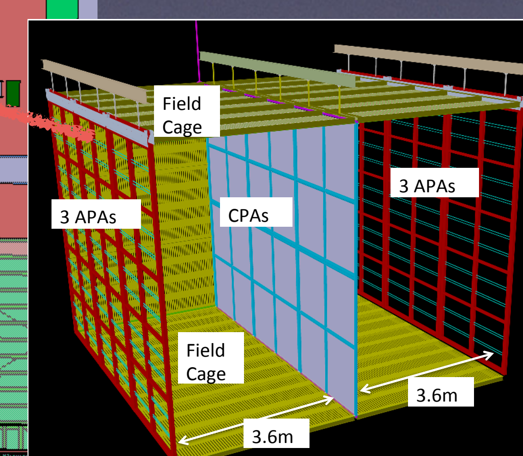
4x(3x3m2 CRP)

Some detector parameters:

- Insulated membrane tank
  → inner volume 8.3x8.3x8.[illegible] m^3
- Active area 36 m^2
- Drift length 6 m
- Total LAr mass 705 ton (~300 ton active)
- Hanging field cage & readout plane
- # of signal channels: 7680 in 12 signal FT
- # of PMTs: 36

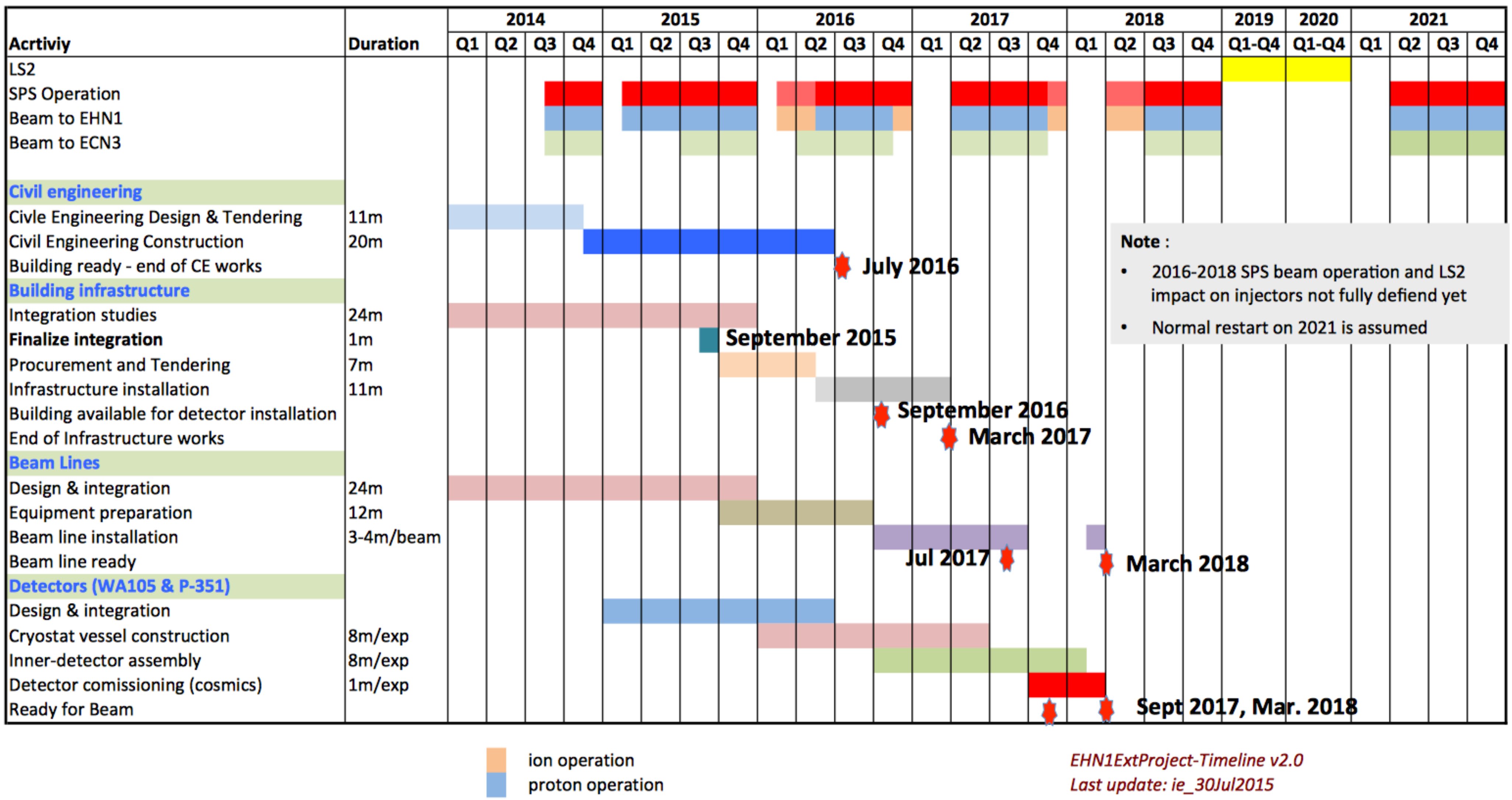
Timescale ≈ 2018

ProtoDUNE



DUNE prototyping: timescale

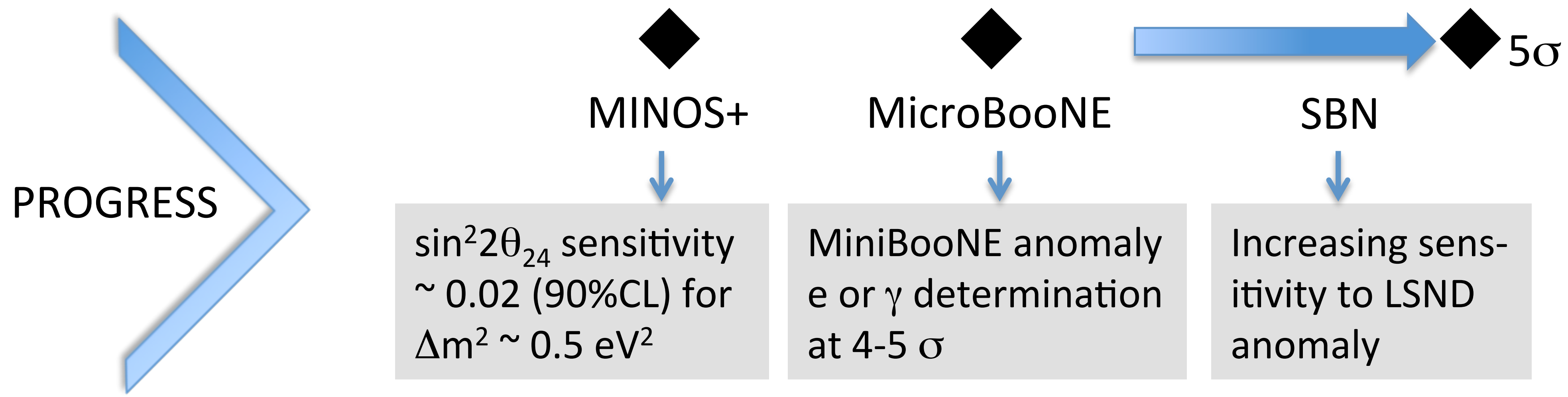
We want to perform these measurements before the LHC LS2 (end of 2018)



This is happening : Cryostats construction in 2016; Detector assembly in 2017

SDN timescale

EPOC	EXPT	2015	2016	2017	2018	2019	2020	
NOW	MINOS+	RUN						
NOW	MicroBooNE		RUN 1		RUN - SBN			
NEXT	SBND		BUILD + INSTALL *		RUN - SBN			
NEXT	ICARUS		REFURBISH+INSTALL*		RUN - SBN			
NEXT+	?						decide	????

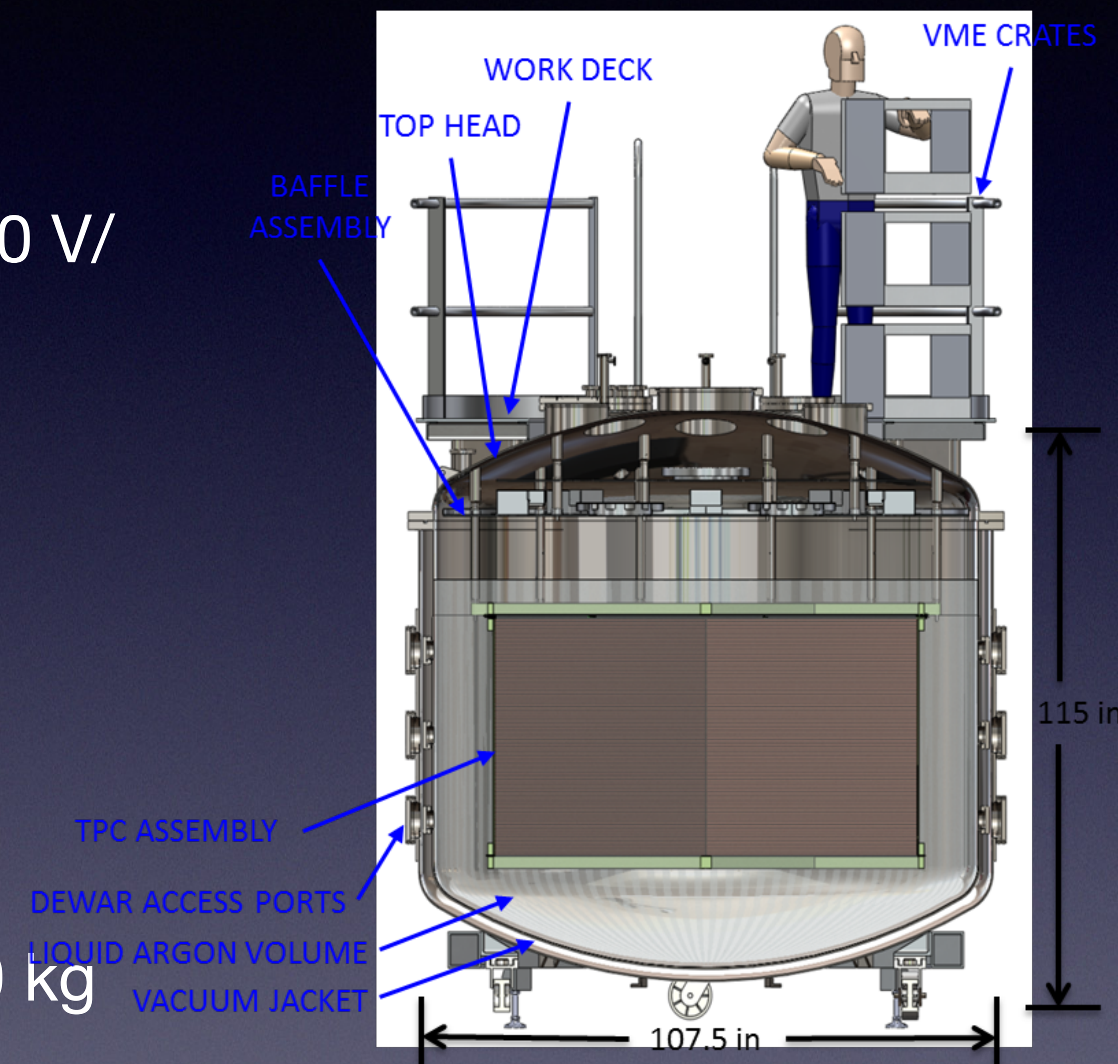


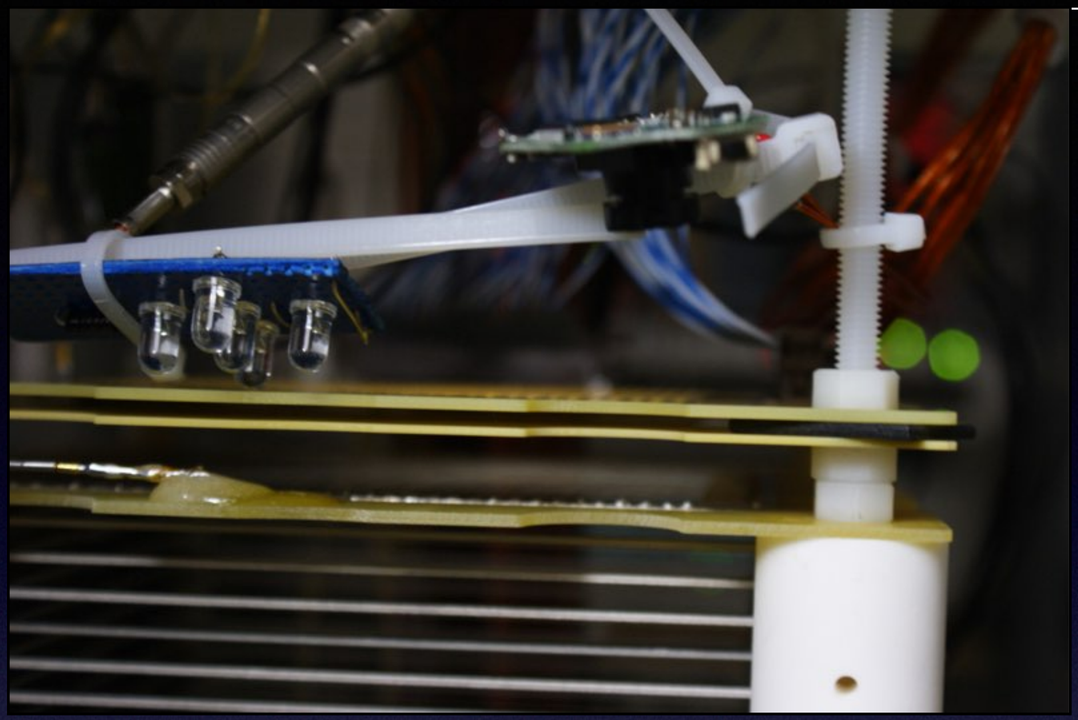
MINOS+	MicroBooNE	SBN
$\sin^2 2\theta_{24}$ sensitivity ~ 0.02 (90%CL) for Δm^2 ~ 0.5 eV^2	MiniBooNE anomaly e or γ determination at 4-5 σ	Increasing sens-itivity to LSND anomaly

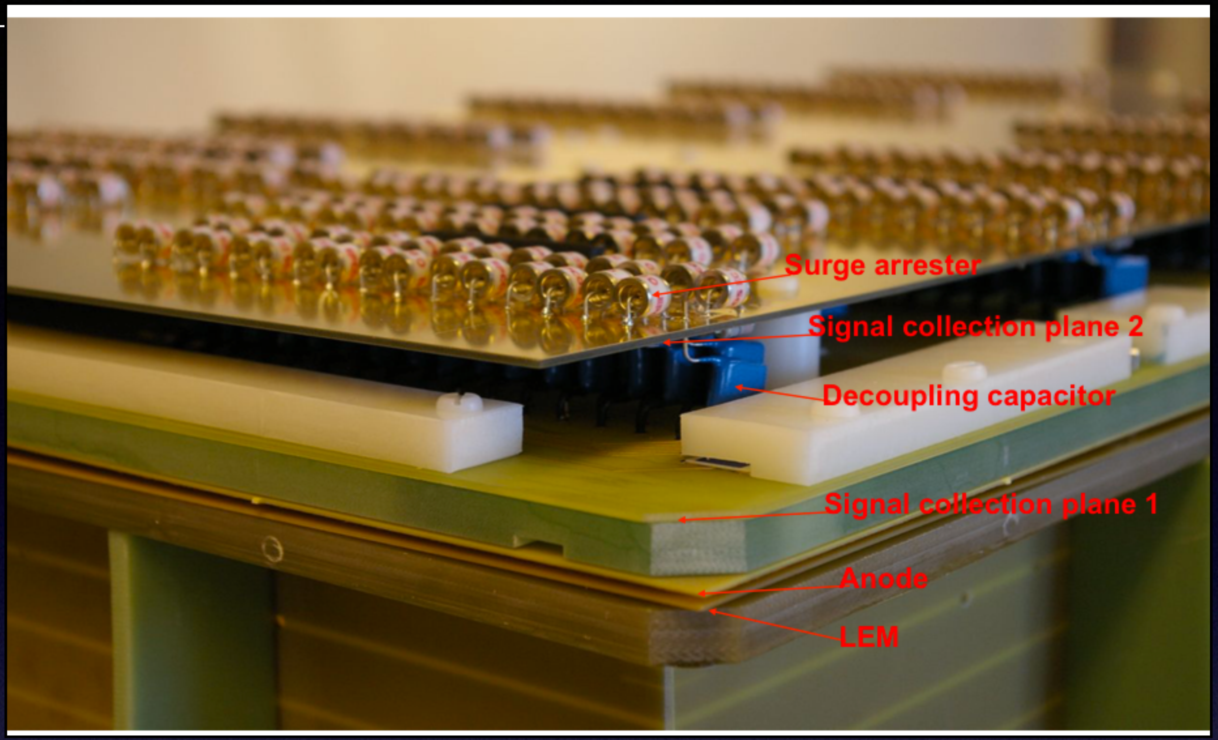
* Important contributions from CERN Neutrino Platform and European funding agencies (INFN, STFC, SNSF)

CAPTAIN

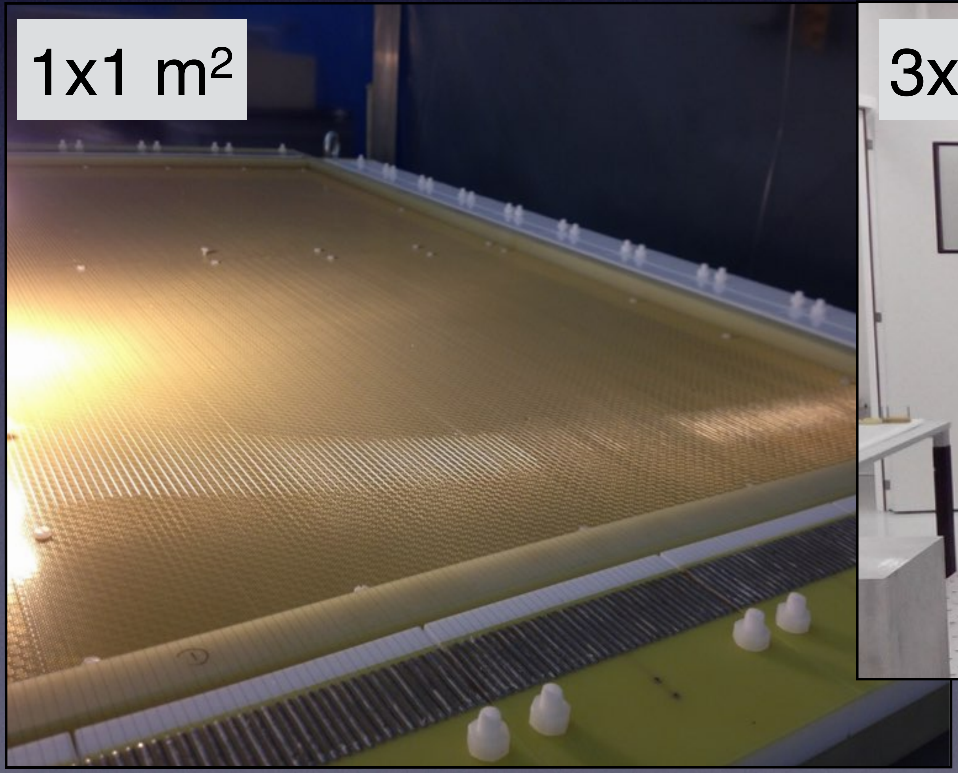
- Liquid argon TPC detector:
  - Portable and evacuable cryostat
  - 5 tons of instrumented liquid argon TPC:
  - Hexagonal prism, vertical upward drift (E = 500 V/cm, v_d = 1.6 mm/μs)
  - 2001 channels (667/plane)
  - 3 mm pitch and wire spacing
- Laser calibration system
- Photon detection system
- Electronics chain is the same as MicroBooNE
- Purification system is a scaled version of MicroBooNE's, similar to LArIAT, based on LAPD experience
- Mini-CAPTAIN: a smaller prototype detector (400 kg of instrumented liquid argon)



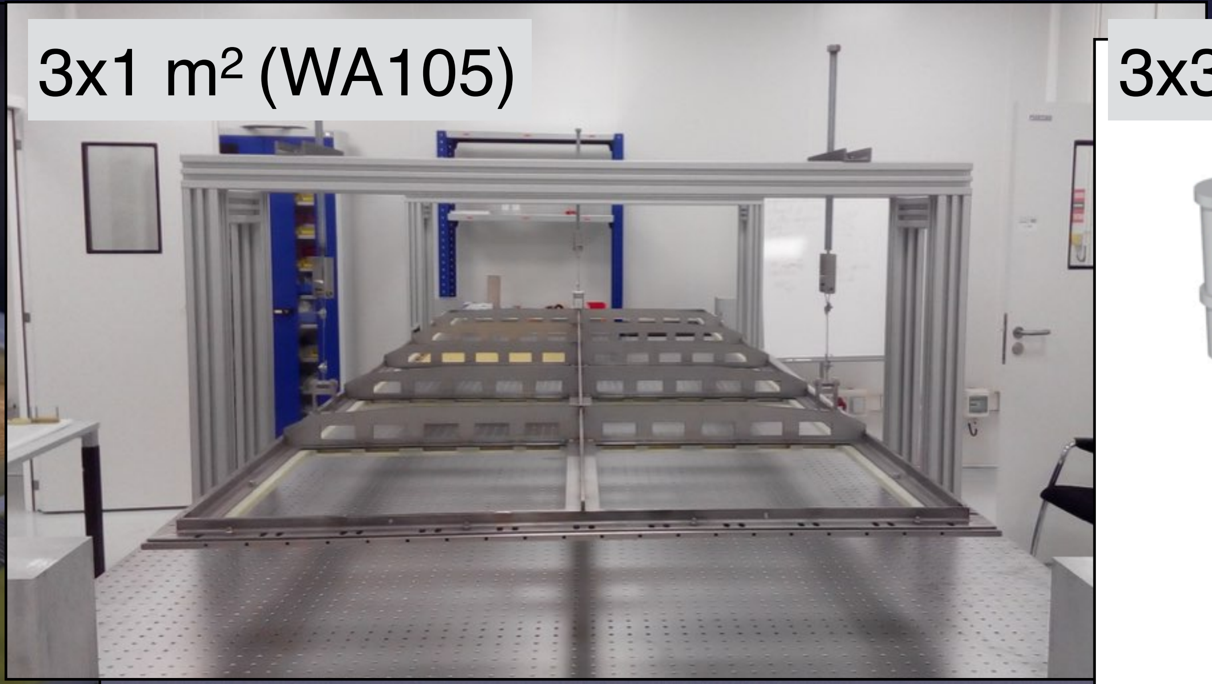




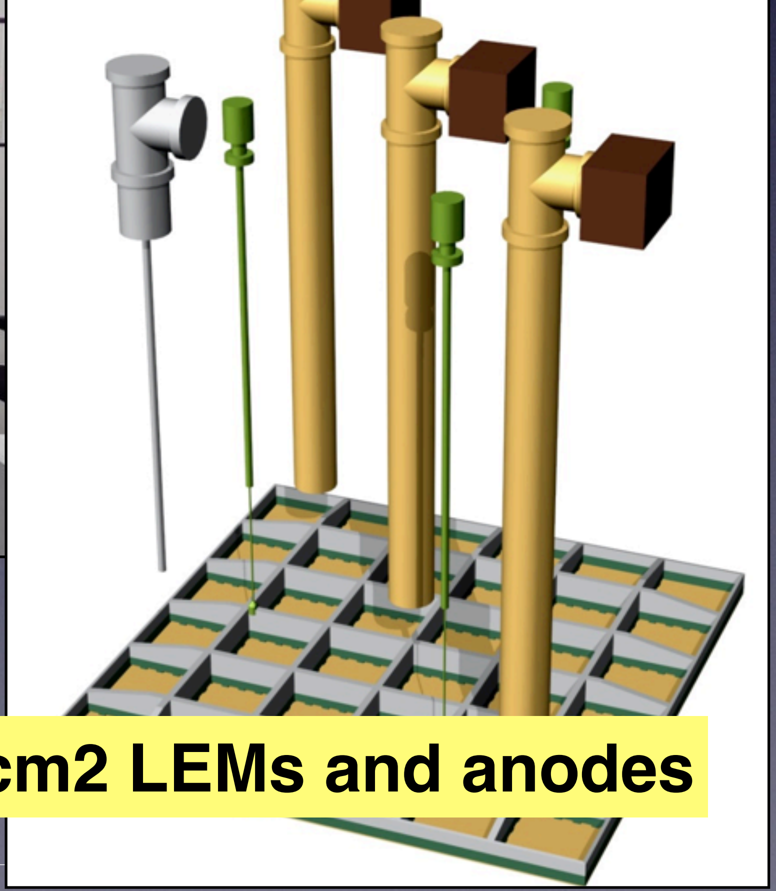
1x1 m²



3x1 m² (WA105)



3x3 m² (WA105 & DUNE)



WA105 and DUNE CRPs are all composed of modules 50x50 cm2 LEMs and anodes

SBN program

EPOC	EXPT	2015	2016	2017	2018	2019	2020	
NOW	MINOS+	RUN						
NOW	MicroBooNE	RUN 1			RUN - SBN			
NEXT	SBND	BUILD + INSTALL *			RUN - SBN			
NEXT	ICARUS	REFURBISH+INSTALL*			RUN - SBN			
NEXT+	?						decide	????

PROGRESS

5σ

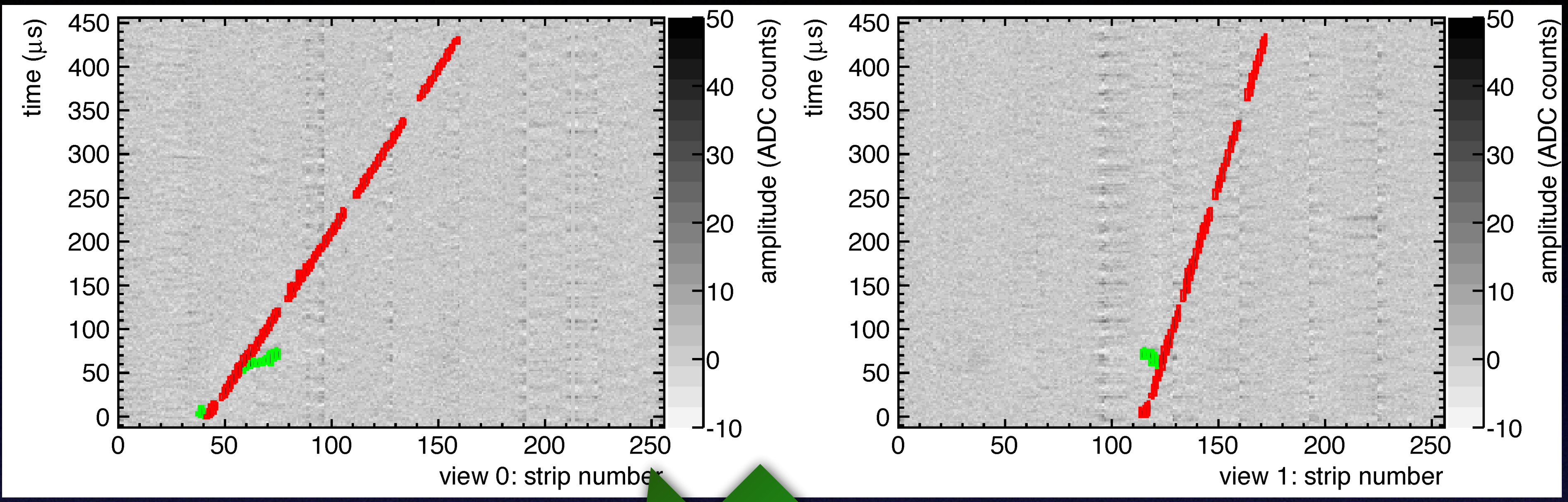
MINOS+ → $\sin^2 2\theta_{24}$ sensitivity ~ 0.02 (90%CL) for Δm^2 ~ 0.5 eV^2

MicroBooNE → MiniBooNE anomaly e or γ determination at 4-5 σ

SBN → Increasing sens-itivity to LSND anomaly

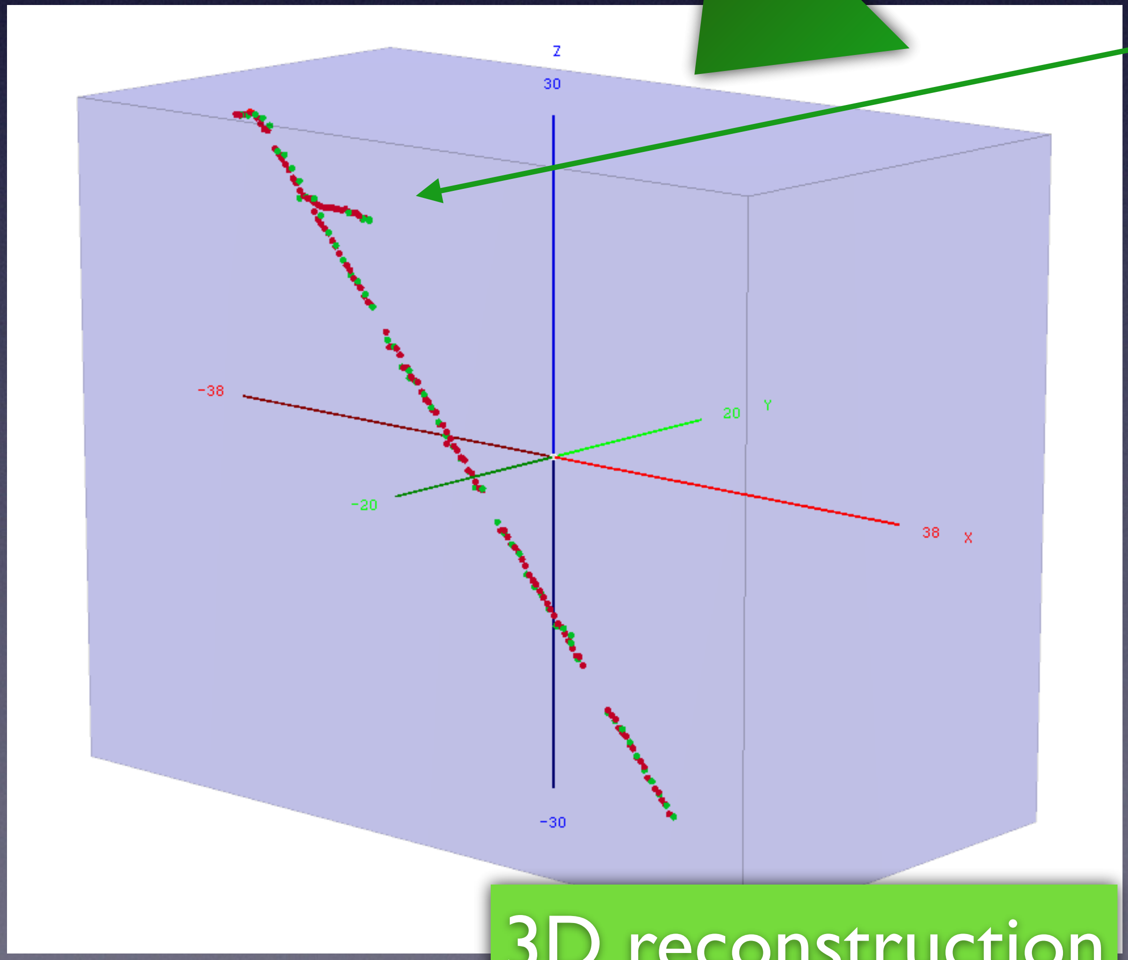
* Important contributions from CERN Neutrino Platform and European funding agencies (INFN, STFC, SNSF)

Efficient reconstruction of delta-rays

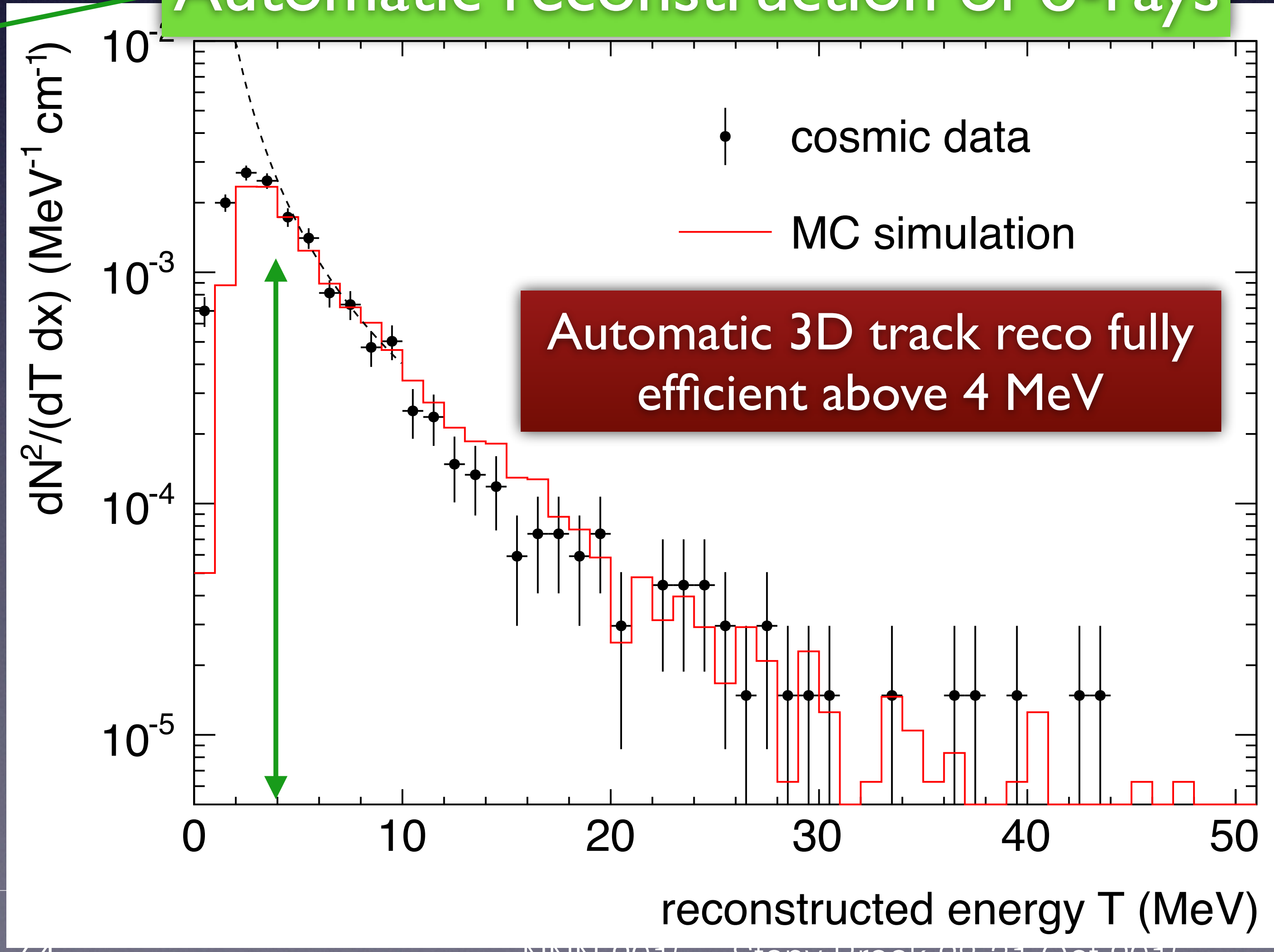


JINST 8 (2013) P04012

Event recorded in 250L double phase chamber exposed to cosmic rays



Automatic reconstruction of δ-rays



Automatic 3D track reco fully efficient above 4 MeV

LAr TPC detectors

Project	LAr mass (tons)	Goal	Baseline (km)	Where	Status
ArgoNEUT	0.25	Neutrino detection	n/a	FNAL	Took data
LArIAT	0.25	Test beam	n/a	FNAL	Took data
CAPTAIN	5	Neutrino detection	n/a	Los Alamos	Construction
MicroBOONE	89	short baseline	0.47	FNAL BNB	Taking data
SBND	112	2nd detector for short baseline	≈0.7	FNAL BNB	Planned 2018
ICARUS	478	3rd detector for short baseline	1.6	FNAL BNB	Took data
DUNE 35T	35	R&D single phase	n/a	FNAL	Construction
WA105 3x1x1m3	25	R&D dual phase	n/a	CERN	Construction
ProtoDUNE	300	Test beam single phase	n/a	CERN	Planned 2018
WA105 6x6x6m3	300	Test beam dual phase	n/a	CERN	Planned 2018
DUNE	4x10000	LBL and astrophysics, nucleon decay	1300	SURF	Planned 2024